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Aspects of Vowel Perception by Normal Hearing and Hearing Impaired Listeners.

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ASPECTS OF VOWEL PERCEPTION BY NORMAL HEARING AND HEARING IMPAIRED LISTENERS

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
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Doctor of Philosophy

in

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and Communication Disorders

by
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ABSTRACT

The effect of durational differences on the identification of vowel tokens was studied using ten normal hearing and six hearing impaired subjects. Stimuli were synthetically generated and varied in duration of the steady state, durations of the initial and final transitions and F1/F2/F3 location. Listeners were required to identify the given vowel token from a set of ten possible alternatives. The results from the normal hearing group supported the established effects of duration on the perception of vowels. However, these effects were different depending on the frequency locations of F1/F2/F3. Further, changes in the duration of the initial transition had a greater effect than changes in the duration of the final transition.

By way of comparison, the identification behavior of the normal hearing subjects was different from the identification behavior of hearing impaired subjects. In particular, the hearing impaired subjects' behavior was idiosyncratic. Further, not only were the subjects different from each other the labelling performance was different within the same subjects across the different vowels.

Thus, the effects of durational changes on vowel identification by normal hearing and hearing impaired listeners differs as a function of formant frequency structure. In addition, the effects of durational changes were dependent on the portion of the vowel that was manipulated. Finally, hearing impaired listeners were not like the normal hearing listeners, nor were they like each other. The results, then can be interpreted to indicate that vowel perception by normal hearing and hearing impaired listeners is a complex multi-cued phenomenon.

CHAPTER I

INTRODUCTION

Traditional accounts of vowel perception have held that the salient cues for vowel perception are found in the spectral cross sections of that acoustic signal (Black, 1949; Delattre, Liberman, Cooper, and Gerstman, 1952; Joos, 1948; Peterson and Barney, 1952; Potter and Steinberg, 1950; and Shephard, 1972). These "target" theories postulate that vowel perception depends on the extraction and use of formant one (F1) and formant two (F2) information.

More recently, Strange and her colleagues have raised questions concerning some limitations of a simple spectral representation of vowel perception (Gottfried and Strange, 1980; Rakerd, Verbrugge, and Shankweiler, 1984; Strange, Edman and Jenkins, 1979; and Verbrugge, Strange, Shankweiler, and Edman, 1976) but (cf. Macchi, 1980). The basis of their questions is the inadequacy of "target" theories in explaining the improved vowel identification performance for vowels that fail to reach their target values. They postulated that vowels are specified by dynamic cues contained in the vowels (Gottfried and Strange, 1980 and Strange, Edman and Jenkins, 1979; and Rakerd 1984). Earlier research by Lindblom and Studdert-Kennedy (1967) and Tiffany (1953) suggested the significance of dynamic information in the vowel identification process.

In addition to dynamic characteristics, Strange, Edman and Jenkins (1979) suggested that intrinsic duration contributes to the specification of vowel quality. While the changes in vowel duration are known to occur in speech production (Lehiste and Peterson, 1961) the contribution of these effects to the perceptual process has received only minor attention (Peterson and Barney, 1952 and Pickett, 1957). An exception to this generality is the work of Ainsworth (1971, 1981) who found duration to be a significant cue in the disambiguation of vowels that were not uniquely specified in the spectral domain.

It appears then that "target" theories of vowel perception may be inadequate in describing the perceptual process for normal hearing subjects. Further, durational cues may be a reasonable addition to the description of the perceptual cue set for the vowels. The lack of success in finding a given set of cues that are important may be related to an ability of normal hearing listeners to use different cues in a somewhat complex manner and thus disguise the underlying cue-set. In other words, vowel perception for normal hearing listeners is a multi-cued complex process.

If "target" theories are inadequate to describe vowel perception for normal hearing listeners, they are even more inadequate to describe the vowel identification process for hearing impaired listeners. That is, hearing impaired listeners may not have access to the spectral information that is necessary to uniquely specify a given vowel. In addition, the common assumption that hearing impaired listeners identify vowels with few errors may not be valid. Evidence to support this common assumption is weak and should be re-explored. Further, little, if any, information is available concerning the ability of hearing impaired listeners to use a multidimensional cue set in the recognition of vowels.

In particular, the previous vowel perception research with hearing impaired listeners (Owens, Talbott, and Schubert, 1968 and Oyer and Doudna, 1959) has been limited for two reasons. First, these researchers used meaningful monosyllabic words which may have given the listeners phonologic as well as acoustic cues. Thus, it is difficult to determine the vowel recognition ability of this group of listeners. Secondly, the use of group data to describe the performance of hearing impaired subjects is suspect. Specifically, Pickett and Martony (1980) and Collins (1984) found considerable variability in the perception of dynamic signals.

Because transition and steady state duration cues, as well as spectral cues, have been found to contribute to the perception of vowels for normal hearing listeners, it might be expected that hearing impaired listeners would also use the same cues. Further, the hearing impaired listeners have an additional challenege imposed by their hearing loss. Specifically, a hearing loss may cause the impaired listeners to use a different cue set or to use the available cue set differently than normal hearing listeners. In addition, because the hearing impaired listener's perceptual system is challenged, there may be an opportunity to obtain insight into possible mechanisms that may be used in the normal vowel perception process.

This study, therefore, was designed to examine the effects of spectral and durational cues on the vowel identification behavior of normal hearing and hearing impaired listeners.

Chapter II

Method

To investigate the effects of durational and spectral cues on the identification of vowels, normal hearing and hearing impaired listeners were asked to identify synthetic vowel-like tokens.

A. Subjects

Ten normal-hearing and six hearing-impaired volunteers served as subjects in this study. The normal-hearing subjects ranged in age between 23 and 46 years and had air conduction thresholds better than or equal to 15 dB HL for the octave frequencies between 250 and 8000 Hz. The hearing impaired subjects ranged in age between 44 and 69 years. Table 1 provides a summary of the audiometric findings for the test ear of the hearing impaired subjects. All hearing impaired subjects reported that their hearing loss began in adulthood.

Table 1. Pure tone air conduction thresholds in dB HL for the hearing impaired subjects for the test ear.

	Frequency (kHz)						Word Recognition
	.25	.5	1.	2.	4.	8.	
Subject							
HI-1	30	45	70	70	60	65	78%
HI-2	15	10	25	65	100	115	54%
HI-3	10	10	10	10	35	65	88%
HI-4	20	10	10	30	80	85	84%
HI-5	15	15	25	35	70	50	84%
HI-6	15	10	20	55	85	90	88%

B. Stimuli

Stimuli were generated using an interactive program that is a modified version of the Klatt (1980) synthesis routines (Miller, 1979). Three five formant vowels (nominally /i/,/I/, and /ɛ/) served as the core of the stimulus set. These vowels were manipulated in each of four dimensions. The four dimensions within which the stimuli were manipulated were as follows: 1) location of the F1, F2, and F3 complex, 2) duration of the steady state portion of the tokens, 3) duration of the onset transition, and 4) duration of the offset transition. As can be seen in Table 2, there were three different F1/F2/F3 complexes for each of the three nominal vowels. The locations of the F1, F2, and F3 complexes were based on formant frequency characteristics reported by Stevens, House and Paul (1966) and Stevens and House (1963). For example, the formant frequency characteristics for the nominal /i/ vowels ($/i/_1$, $/i/_2$, $/i/_3$) were those reported by Stevens et al. (1966) and Stevens and House (1963). Thus the frequency values for the nominal vowel $/i/_1$ were those of an /i/ vowel as it might be produced in isolation (Peterson and Barney, 1952). Similarly, the frequency values for the nominal vowel $/i/_2$ were those of /i/ vowels as they might be produced in a /sis/ condition. Finally, the values for

$/i/_3$ were those for an /i/ vowel in a "neutral" context (i.e. the mean of each formant frequency of the vowel /i/ as it is produced in isolation and in a /hvd/ context). The formant frequency values for the remaining nominal vowels (/I/, and /ɛ/) were determined in a similar manner.

The steady state duration conditions are summarized in Table 3. The duration values ranged from 24 ms to 280 ms. This range of values includes steady state durations that are appropriate for each of the nominal vowels (House, 1961, and Lehiste and Peterson, 1961). All eleven durations were used in the data collection process with the normal hearing subjects. In contrast, only those durations marked with an asterisk were used in the data collection process with the hearing impaired subjects.

Finally, the duration conditions listed in Table 4 are for of the initial and final transition duration values. The initial transition duration conditions ranged from 8 ms to 112 ms and the final transition duration conditions ranged from 8 ms to 132 ms. Also, for each of the above conditions there was a no-transition (or steady state only) condition. There were 12 transition conditions for /i/ and /ɛ/ and 11 transition conditions for /I/. For those conditions in which the initial transition was varied, the final transition was fixed; similarly, when the final transition was varied the initial transition was fixed. The

Table 2. Formant frequency values (Hz) for all versions of the nominal /i/, /I/, /ɛ/ . Those nominal vowels with a subscript of 1 had formant frequency values that were appropriate for the vowel as it would be produced in isolation. For those marked with a subscript of 2, the formant frequencies were appropriate for the vowel as produced in /svs/. Finally, for those nominal vowels with a subscript of 3, the formant frequency values were a mean of each of the formant frequency values for vowels produced in isolation and in an /hvd/ context.

Vowel	F1	F2	F3
$/i/_1$	300	2340	2920
$/I/_1$	460	2030	2670
$/\ \ /_1$	580	1880	2570
$/i/_2$	280	2320	2950
$/I/_2$	450	2000	2650
$/\varepsilon/_2$	530	1910	2690
$/i/_3$	280	2220	2950
$/I/_3$	450	1740	2650
$/\varepsilon/_3$	530	1690	2690

Table 3. Durations of the steady state portions for all three version the nominal vowels /i/, /I/ and /ɛ/. Those marked with an asterisk were the subset of stimuli used for the hearing impaired listeners.

Condition	Duration (ms)
1 *	024
2	056
3 *	072
4	088
5 *	104
6 *	120
7	152
8	184
9 *	200
10	232
11 *	280

Table 4. Initial and final formant transition durations (ms) for all versions of the nominal vowels /i/,/I/, and /ɛ/.

	/i/		/I/		/ɛ/	
	initial	final	initial	final	initial	final
1	none	none	none	none	none	none
2	16	48	---	---	8	100
3	32	48	8	80	24	100
4	48	48	24	80	40	100
5	64	48	40	80	56	100
6	80	48	56	80	72	100
7	96	48	72	80	88	100
8	112	48	88	80	104	100
9	---	---	40	32	56	52
10	64	16	40	48	56	68
11	64	32	40	64	56	84
12	64	64	40	96	56	116
13	64	80	40	112	56	132
14	64	96	---	---	---	---

values for the fixed transitions were based on data presented by Lehiste and Peterson (1961). The endpoint frequency locations for the transitions were fixed and were based on the data reported by Stevens, House and Paul (1966). Because the endpoint frequencies were fixed and the duration of the transition portions changed, the stimuli also varied in the rate of frequency modulation of the initial and the final transition portions.

The manipulations of the four physical dimensions resulted in the generation of 1254 possible stimuli. The normal hearing subjects listened to all possible tokens, while the hearing impaired subjects listened to a 456 member subset of the entire corpus. (For further details concerning stimulus generation and physical characteristics of the stimuli, please see Appendix B.)

The vowel-like tokens were stored in digital form and output in analog form by means of a Metrabyte Dash-16 D/A board at a rate of 10kHz. For the normal hearing subjects, signals were low pass filtered at 4800 Hz with a Wavetek Rockland Brickwall filter (model 752A) and passed through a Hewitt-Packard attenuator set (model 305D). For the hearing impaired subjects, an additional stage of amplification using a Sansui amplifier (model 707-A) was inserted following the attenuation stage and prior to the signal output through a Sennheiser (model HD430) earphone.

(See Appendix C for further description of instrumentation and calibration.)

For the normal hearing subjects, the stimuli were randomly assigned to one of 26 lists; with each list composed of 50 vowel tokens. These lists were presented to the listeners in a random order. For the hearing impaired listeners, the items of the subset of stimuli were randomly assigned to one of 10 lists. Again, the lists were composed of 50 items and the lists were presented to the hearing impaired listeners in a random order with the tokens also presented in random order. Because the number of stimuli was not a factor of 50, the final list for each subject group consisted of a repitition of some of the tokens (i.e. 46 tokens and 44 tokens were repeated for the normal and hearing impaired subjects respectively. These responses were not included in the data analysis.) The normal hearing subjects listened to two replications (without replacement) for each of the 50 stimuli in each list. The hearing impaired subjects listened to three replications (without replacement) for each of the 50 stimuli in each list. Prior to participation in the experiment, the normal hearing listeners were given oral instructions and practice, if necessary. The hearing impaired subjects were also instrucuted orally and they underwent a 20 minute practice period. During that period the subjects listened to tokens that were not part of the experimental stimulus set and were asked to respond by striking the appropriate response key. There was not an attempt to evaluate the correctness of the response as one of the goals of this experiment was to examine individual perceptual behavior; thus, the concept of correct/incorrect is not appropriate. All subjects completed the practice run with little difficulty and participated in the entire experiment. Each experimental session lasted approximately 40 minutes, during which subjects listened to three 50-item sets. Subjects were instructed to take breaks as necessary between each set.

C. Experimental Condition

All subjects listened to each of the vowel tokens monaurally through a Sennheiser earphone (model HD430) while seated in a double walled IAC test booth. These tokens were presented at 84 dB SPL peak for both the normal hearing and the hearing impaired listeners.

Stimulus generation and experimental procedures were controlled with an interactive identification program written for an IBM AT microprocessor and a Metrabyte Dash 16 D/A board. Subjects were instructed to identify each token by means of selecting their responses from a list of ten alternatives. The orthographically represented alternatives were: heed, hid, head, had, hod, hawed, hood, who'd, hud, and heard. Subjects entered their responses by striking the appropriate key on the computer keyboard.

CHAPTER III

RESULTS

The results of the present experiment contain vowel identification data for normal hearing and hearing impaired subjects. Because the synthetic vowel tokens were manipulated in terms of steady state duration, initial and final transition durations, and vowel formant structure, the data will be reported with respect to these parameters. Particularly, for each vowel formant-frequency structure (i.e., nominal vowel) the effects of steady state and transition durations will be reported for the normal hearing and hearing impaired subjects. In general, the effects were such that the labels assigned by the listeners changed from one vowel to another. The results, then, will be presented in terms of the shifts in labeling as well as descriptions of the percent of identification of the nominal vowel. Because there were few differences in the results for stimulus pairs $/i/_1$-$/i/_3$, $/I/_1$-$/I/_3$, and

$/\varepsilon/_1$-$/\varepsilon/_3$, only the results for the nominal vowels $/i/_1$, $/i/_2$, $/I/_1$, $/I/_2$, $/\varepsilon/_1$, $/\varepsilon/_2$ will be reported.

Nominal Vowels $/i/_1$ and $/i/_2$

Normal Hearing Subjects

1. Steady State Duration. When presented with steady state durations of various lengths of the nominal vowel /i/, listeners primarily reported perception of /i/. The total number of /i/ responses for all subjects for each steady-state by transition-duration condition are presented in Tables 5 and 6. These matrices are organized such that the columns represent steady-state duration conditions and the rows represent transition-duration conditions. It should be noted that the results in the fourth row in the initial transition duration (ITD) condition and the fourth row in the final transition duration (FTD) condition represent the same data and are simply repeated to complete the table (this convention was followed for the remaining tables). Table 5 contains the responses to the nominal vowel $/i/_1$. The formant structure of the vowel-like token used to obtain the responses summarized in Table 5 was F1=300 Hz, F2=2340 Hz, and F3=2920 Hz. Similarly, Table 6 contains the response to the nominal

Table 5. A summary of the total number of /i/ responses by normal hearing subjects to the nominal vowel /i/$_1$ (max=20). (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	17	20	19	19	20	20	19	18	19	20	20
16	16	15	20	18	18	20	20	19	20	20	20
32	18	20	18	19	19	19	18	18	20	19	20
48	20	20	20	20	20	20	19	20	20	20	20
64	20	20	19	19	19	20	19	20	19	20	20
80	19	20	18	19	20	20	20	20	20	20	20
96	19	20	20	19	20	20	20	20	19	19	20
112	19	20	20	20	20	20	20	20	20	20	20
FTD (ms)											
16	20	20	20	20	20	19	19	20	20	20	20
32	19	20	19	19	19	19	20	20	19	19	20
48	20	20	19	19	19	20	19	20	19	20	20
64	20	19	19	19	20	19	20	20	20	20	20
80	17	19	19	20	20	20	20	20	19	19	20
96	20	19	20	19	20	20	20	17	20	20	20

Table 6. A summary of the total number of /i/ responses by normal hearing subjects to the nominal vowel /i/$_2$ (max=20). (Note: ITD=initial transition duration, FTD= transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	19	18	19	17	20	20	19	19	20	20	19
16	17	16	19	17	19	19	18	20	20	20	20
32	16	19	20	18	18	20	19	20	20	20	20
48	19	19	19	20	20	19	20	20	20	20	20
64	19	19	19	19	20	20	18	20	20	20	20
80	19	19	19	20	20	20	20	19	20	20	19
96	19	20	19	19	18	18	20	20	20	20	20
112	20	20	19	20	20	20	20	20	20	20	20
FTD (ms)											
16	20	20	20	20	20	20	20	20	20	20	20
32	19	20	20	20	20	20	20	20	20	20	20
48	19	19	19	20	20	19	20	20	20	20	20
64	20	20	20	19	19	19	20	20	20	20	19
80	19	17	19	20	20	20	20	19	20	19	20
96	17	20	19	19	19	20	19	19	19	19	19

vowel $/i/_2$. The formant structure used to obtain the responses for Table 6 was F1=280 Hz, F2=2320 Hz, and F3=2950 Hz.

The primary factor that appeared to affect responses is short steady state durations. In Table 5, for example, the number of /i/ responses to $/i/_1$ is smaller for the shorter steady state durations ($\leq$56 ms). Similarly, fewer /i/ responses were reported for the short steady state durations (< 56 ms) for the nominal vowel $/i/_2$ (Table 6). If /i/ was not a viable response for the short duration steady state conditions, listeners chose /I/.

2. <u>Initial Transition Duration.</u> Again, with reference to Tables 5 and 6, some general trends are observable. These trends are weak yet consistent. That is, with long initial transitions (e.g., $\geq$ 48 ms), listeners were more likely to identify the stimuli as /i/. However, if the initial transitions were shorter, listeners tended to identify the stimuli as /I/.

Also, as can be oberved in Tables 5 and 6, there is an apparent interaction between the initial transition durations and the steady state durations. That is, as the steady state duration lengthens, there appears to be little effect of the initial transition. However, at shorter steady state durations the initial transition appears to contribute to shifts in perception of the stimulus. The frequency with which /i/ was chosen as a response is lower for short initial transition conditions relative to the longer initial transitions, holding steady state duration fixed.

3. Final Transition Duration. The apparent effects of the initial transition and the interaction between that transition and the steady state duration does not hold for the final transition duration conditions. The frequency of /i/ responses remains high in spite of changes in the final transition duration. For those few isolated conditions in which /i/ was not chosen, /I/ was the alternative response.

In summary, normal hearing listeners reported /i/ as the primary response for the nominal vowels $/i/_1$ and $/i/_2$. While the effects of the manipulations of duration were slight, the general trends observed were shifts in labels from the vowel /i/ to the vowel /I/ if the durations of the steady state and the initial transitions were sufficiently short (i.e., $\leq$ 56 ms). There appeared to be little, if any, effect of the final transitions duration changes. Also, the changes in formant frequency structure between the two nominal vowels did little to alter the apparent trends.

Hearing Impaired Listeners

Because the six hearing impaired subjects were different with regard to their response patterns, they will be considered individually. Tables 7 through 18 contain summaries of each of the hearing impaired listeners response patterns. The response patterns are presented in terms of the labels that the individual listeners assigned to each of the tokens. Again, these response matrices are organized such that the columns represent steady state duration conditions while the rows represent transition duration conditions. Responses are reported for those cases in which listeners responded with more than 65% consistency. If the consistency was less than 65%, then it was concluded that there was not a reliable response. Those stimuli that were not labeled consistently are indicated as empty cells in the tables. Tables 19 and 20 provide a summary of the normal hearing listeners response patterns. These have been collapsed over subjects and are included to serve as a basis of comparison for the hearing impaired data. Again, the reported response must have been chosen with 65% or greater consistency to be included in the response table. Because the hearing impaired listeners were given a subset of the steady state durations conditions given to the normal hearing subjects, Tables 7

Table 7. Response table for hearing impaired subject HI-1. The nominal vowel $/i/_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		I		I	a			i		
16			I		I				i		i
32	I					I			I		ε
48			i			i					i
64	I		ε		i				i		
80	i		i			i					
96			i			ε			ε		I
112					i	ε					
FTD (ms)											
16			I		I	ε			I		ε
32	I		i			æ					ε
48	I		ε		i				i		
64					i						ʊ
80	ε					ε			i		ʊ
96	i		i		i						

Table 8. Response table for hearing impaired subject HI-1. The nominal vowel $/i/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		i			I			I		
16	I		I		i				æ		i
32	ɛ					I			i		
48			I		ɛ						i
64	ɑ		i			i					
80	I		i		I						
96	i										I
112	i				ɛ	ɛ					
FTD (ms)											
16	I		I		I				I		
32	I		i			I					
48	I				i	i			i		i
64	I				i	i					
80	I								i		
96	i		i		i						i

Table 9. Response table for hearing impaired subject HI-3. The nominal vowel $/i/_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		I		I	I			i		i
16	I		I			I			i		i
32	ɛ		I			ɛ					i
48					ɛ	ɛ			i		i
64					ɛ	ɛ			i		i
80	ɝ		ɛ		ɛ	ɛ			i		i
96	ɛ		ɛ		ɛ	ɝ			i		i
112	ɛ				ɛ				i		i
FTD (ms)											
16			ɛ		ɝ	ɝ			ɛ		i
32	I		ɛ		ɝ	ɝ					ɛ
48			ɛ		ɛ	ɛ			i		i
64					ɝ	i			i		i
80	I		ɛ		i	i			i		i
96			ɛ		ɛ	ɝ			i		i

Table 10. Response table for hearing impaired subject HI-3. The nominal vowel $/i/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		I		I	ɛ			i		i
16	I		I		ɛ	ɛ					ɛ
32	I		I			ɛ			ɛ		i
48	I		ɛ			ɛ					i
64	ɛ		i		ɛ	i			i		i
80	I		ɛ		ɛ	ɝ			i		i
96						ɝ			i		i
112	ɛ		ɛ		ɛ	i			i		i
FTD (ms)											
16	I		I		ɛ	ɛ			i		i
32	I		ɛ			ɛ			ɛ		i
48	ɛ		i		ɛ	i			i		i
64	I				ɛ	i					i
80			ɛ		ɛ	ɛ			ɛ		i
96			ɛ		ɛ	i			i		i

Table 11. Response table for hearing impaired subject HI-2. The nominal vowel /i/$_1$ served as stimulus. (Note: ITD=initial transtion duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i				i				i		i
16	ɝ		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		ɛ		i	i			i		i
96	i		i		i	i			i		i
112	i		i		i	i			i		i
FTD (ms)											
16	i				i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i

Table 12. Response table for hearing impaired subject HI-2. The nominal vowel $/i/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		i		i				i		i
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48			i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i
112	i		i		i	i			i		i
FTD (ms)											
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i

Table 13. Response table for hearing impaired subject HI-4. The nominal vowel $/i/_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i		i		i	i			i		i
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i
112	i		i		i	i			i		i
FTD (ms)											
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i

Table 14. Response table for hearing impaired subject HI-4. The nominal vowel $/i/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i		i		i	i			i		i
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i
112	i		i		i	i			i		i
FTD (ms)											
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i

Table 15. Response table for hearing impaired subject HI-5. The nominal vowel /i/$_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i		i		i	i			i		i
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i
112	i		i		i	i			i		i
FTD (ms)											
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i

Table 16. Response table for hearing impaired subject HI-5. The nominal vowel $/i/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i		i		i	i			i		i
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i
112	i		i		i	i			i		i
FTD (ms)											
16	i		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i

Table 17. Response table for hearing impaired subject HI-6. The nominal vowel $/i/_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i		i		I	i			i		i
16	I		i		i	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i
112	i		i		i	i			i		i
FTD (ms)											
16	i		i		i	i			i		i
32			i		I	I			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i

Table 18. Response table for hearing impaired subject HI-6. The nominal vowel $/i/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i		I		I	i			i		i
16	i				i	i			i		i
32	i		i		i	i			i		i
48	i				i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i
112	i		i		i	i					i
FTD (ms)											
16	i		i		I	i			i		i
32	i		i		i	i			i		i
48	i		i		i	i			i		i
64	i		i		i	i			i		i
80	i		i		i	i			i		i
96	i		i		i	i			i		i

through 18 have blank columns for the 56 ms, 88 ms, 152 ms, 184 ms, 232 ms steady state duration conditions.

1. Steady State Duration. The data for hearing impaired subject 1 (HI-1) are included in Tables 7 and 8. It is apparent that if /i/ was not reliably chosen, this subject's response pattern changed with increasing duration, with /i/ reliably chosen only at long steady state durations. In addition, at some of the long duration conditions /ɛ/ was a viable alternative response. Similar to the normal hearing subjects, /I/ was a reasonable alternative for the short steady state durations. For the normal hearing listeners, formant frequency differences between the nominal vowels $/i/_1$ and $/i/_2$ was neglible; however, for this particular listener the response patterns were different for the two nominal /i/ tokens. At the longest steady state duration (280 ms) and lowest F1/F2/F3 conditions, /i/ was the response of choice for those stimuli that were reliably labeled. In contrast, for the higher F1/F2/F3 conditions, /i/, /I/ and /ɛ/ were reliably chosen.

These response patterns indicate that changing steady state duration is effective, as there are corresponding changes in the assigned labels. In addition, for this subject, there is considerable variability in the response

Table 19. Response table for normal hearing subjects for the nominal vowel /i/$_1$. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i	i	i	i	i	i	i	i	i	i	i
16	i	i	i	i	i	i	i	i	i	i	i
32	i	i	i	i	i	i	i	i	i	i	i
48	i	i	i	i	i	i	i	i	i	i	i
64	i	i	i	i	i	i	i	i	i	i	i
80	i	i	i	i	i	i	i	i	i	i	i
96	i	i	i	i	i	i	i	i	i	i	i
112	i	i	i	i	i	i	i	i	i	i	i
FTD (ms)											
16	i	i	i	i	i	i	i	i	i	i	i
32	i	i	i	i	i	i	i	i	i	i	i
48	i	i	i	i	i	i	i	i	i	i	i
64	i	i	i	i	i	i	i	i	i	i	i
80	i	i	i	i	i	i	i	i	i	i	i
96	i	i	i	i	i	i	i	i	i	i	i

Table 20. Response table for normal hearing subjects for the nominal vowel $/i/_2$ (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	i	i	i	i	i	i	i	i	i	i	i
16	i	i	i	i	i	i	i	i	i	i	i
32	i	i	i	i	i	i	i	i	i	i	i
48	i	i	i	i	i	i	i	i	i	i	i
64	i	i	i	i	i	i	i	i	i	i	i
80	i	i	i	i	i	i	i	i	i	i	i
96	i	i	i	i	i	i	i	i	i	i	i
112	i	i	i	i	i	i	i	i	i	i	i
FTD (ms)											
16	i	i	i	i	i	i	i	i	i	i	i
32	i	i	i	i	i	i	i	i	i	i	i
48	i	i	i	i	i	i	i	i	i	i	i
64	i	i	i	i	i	i	i	i	i	i	i
80	i	i	i	i	i	i	i	i	i	i	i
96	i	i	i	i	i	i	i	i	i	i	i

alternatives and a large number of conditions in which a reliable response could not be found. Transition durations appear to affect this pattern.

Similar to the responses of subject HI-1, subject HI-3 reliably labeled long duration tokens as /i/. However, as can be seen in Tables 9 and 10 this subject reliably labeled more conditions and the response set was smaller than that of HI-1. In general, subject HI-3 tended to label the stimuli as /I/ at short durations (24-72 ms), /ɛ/ at middle durations (104-120 ms), and /i/ at long durations (200-280 ms). As for the results with subject HI-1, the response pattern for subject HI-3 also appears to be affected by the initial transition; yet in contrast to HI-1, HI-3 appears to be insensitive to the differences in F1/F2/F3 structure.

The response patterns for the four remaining hearing impaired subjects were similar to each other and thus they will be considered as a group. These subjects were similar to HI-1 and HI-3 in their responses to the long duration stimuli. That is, they too responded to the long duration tokens as /i/. They differ, however, from the other two impaired subjects and appear to be more like the normal hearing subjects in their responses to shorter tokens. The response patterns for these subjects are included in Tables 11 through 18. As will be recalled, the trend in the response alternatives for the normal hearing subjects was to label shorter durations items as /I/ although their responses were typically /i/. For this group of hearing impaired listeners, the response of choice was /I/ for the short duration items. These listeners, as well as subject HI-3, consistently labeled more of the stimuli reliably than did subject HI-1. In contrast to subjects HI-1 and HI-3, and similar to the normal hearing subjects, this group of hearing impaired subjects showed some trends in terms of the effects of transitions. This effect, however, is somewhat weak. Also, differences in F1/F2/F3 structure had no effect on the response patterns.

By way of summary, there appeared to be idiosyncratic differences among the hearing impaired subjects. In addition, there were differences between the hearing impaired group and the normal hearing group.

2. <u>Initial Transition Duration.</u> For subject HI-1, increasing the duration of the initial transition serves to decrease the number of reliably labeled stimuli. This is indicated by the increased number of empty cells for the longer initial transition duration conditions. Subject HI-3, in contrast, reliably chose /ɛ/ as the response to stimuli with longer initial transitions. The ability to reliably label the stimuli was also a hallmark of the

remaining hearing impaired subjects. However, the remaining subjects differed from subject HI-3 because they reliably chose either /i/ or /I/ as their responses. These responses were more typical of the trends observed in the normal hearing group.

In addition, for subjects HI-1 and HI-3 there appears to be a trade-off between the steady state duration and the initial transition. For subject HI-1, increasing the duration of the initial transition while maintaining a short steady state generates the same response as a long steady state portion with a short initial transition. While this trading is somewhat erratic for subject HI-1, the trading is consistent for subject HI-3. This can be observed by evaluating the responses on the diagonals rising from left to right in Tables 9 and 10. A similar trade-off is not observed for the remaining hearing impaired or normal hearing subjects.

3. Final Transition Duration. For subject HI-1, increasing the duration of the final transition has the effect of increasing the number of stimuli that could not be reliably labeled. As will be recalled, this effect is similar to that experienced by this listener with changes in the initial transition duration. The response patterns for subject HI-3 also changed with increases in final

transition duration. As with the initial transition conditions, this subject consistently labeled the longer final transition stimuli as /ɛ/ within a given steady state duration. As noted previously, this subject labeled most of the stimuli reliably so that the effect of changing final transition duration was to change the response pattern rather than to diminish the reliability of labeling. Again a trade-off between final transition duration and steady state duration is evident for subject HI-3. Such a trading is not apparent for subject HI-1.

For the remaining hearing impaired subjects, changes in final transition duration did little to change the response patterns. These results are similar to those found for the normal hearing subjects. Specifically, /i/ was the primary response, and in those few cases in which /i/ was not chosen, /I/ was the alternative.

In summary, the hearing impaired listeners vary both in their response patterns and the reliability with which they labeled the stimuli. Subject HI-1 was the most variable in terms of the response pattern and reliability of labeling. Subject HI-3 was able to reliably label the majority of the stimuli even though the response pattern was different from the other listeners. In addition, this subject demonstrated a trade-off between the initial transition duration and the steady state duration and a trade-off between the final transition duration and the steady state duration. The remaining hearing impaired subjects were more like the normal hearing subjects in terms of their response patterns and the reliability with which the stimuli were labeled. In contrast, the hearing impaired subjects labeled more of the short duration stimuli as /I/ while the normal hearing subjects labeled them as /i/.

Nominal Vowels $/I/_1$ and $/I/_2$

Normal Hearing Subjects--$/I/_1$

Because there was a clear divergence in the response patterns related to the formant structure for the nominal vowels $/I/_1$ and $/I/_2$, the results for the nominal vowel $/I/_1$ with formant structure F1=460 Hz, F2=2030 Hz, and F3=2670 Hz will be presented first. Following will be the results for the nominal vowel $/I/_2$ with formant structure F1=450 Hz, F2=1740 Hz, and F3=2650 Hz.

1. Steady State Duration. The total number of /I/ responses for all normal hearing subjects for each steady-state by transition-duration condition is presented in

Table 21. It can be seen that as steady state duration increases, the number of /I/ responses decreases. Further, as can be seen in Figure 1, the previously observed decrease in /I/ responses was accompanied by an increase in the number of /ε/ responses as steady state duration increased. It is apparent that with increasing steady state duration, listeners experience at least two related changes. As the steady state portion of the stimuli increases in duration the number of /I/ responses decreases and the number of /ε/ responses increases. This implies that stimuli with the same formant frequency components generate apparently two different labels, /I/ and /ε/. It should be noted that this effect is particularly evident for a subset of the initial and final transition conditions.

The responses summarized in Figure 2 are for stimuli with 8 ms initial transitions. Again, the number of /I/ responses decreases with increases in steady state duration. Comparisons among Figures 2, 3, and 4 illustrate the changes in the effect of steady state duration with increases in initial transition duration. That is, the initial transition duration for the stimuli used to generate the responses summarized in Figure 3, was longer than the initial transition for the stimuli used in

Table 21. A summary of the total number of /I/ responses by normal hearing subjects to the nominal vowel /I/$_1$ (max=20) (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	12	6	12	14	13	9	10	9	11	5	5
8	15	12	10	12	13	11	6	4	1	2	2
24	8	13	4	8	5	8	0	9	6	9	1
40	14	11	10	5	2	9	5	4	2	8	2
56	4	6	5	4	9	3	3	5	7	4	0
72	9	8	7	3	5	6	1	5	5	4	4
88	7	2	2	2	6	2	3	4	7	4	4
FTD (ms)											
32	11	3	11	4	6	8	7	3	1	1	3
48	12	9	13	4	10	8	4	5	7	4	6
64	9	7	13	8	12	4	5	3	3	9	1
80	14	11	10	5	2	9	5	4	2	8	2
96	6	6	6	2	4	2	8	4	3	3	5
112	8	8	6	8	1	6	4	5	4	6	3

Figure 1. Number of responses as a function steady state duration. The nominal vowel /I/ i_1 without transitions served as stimulus.

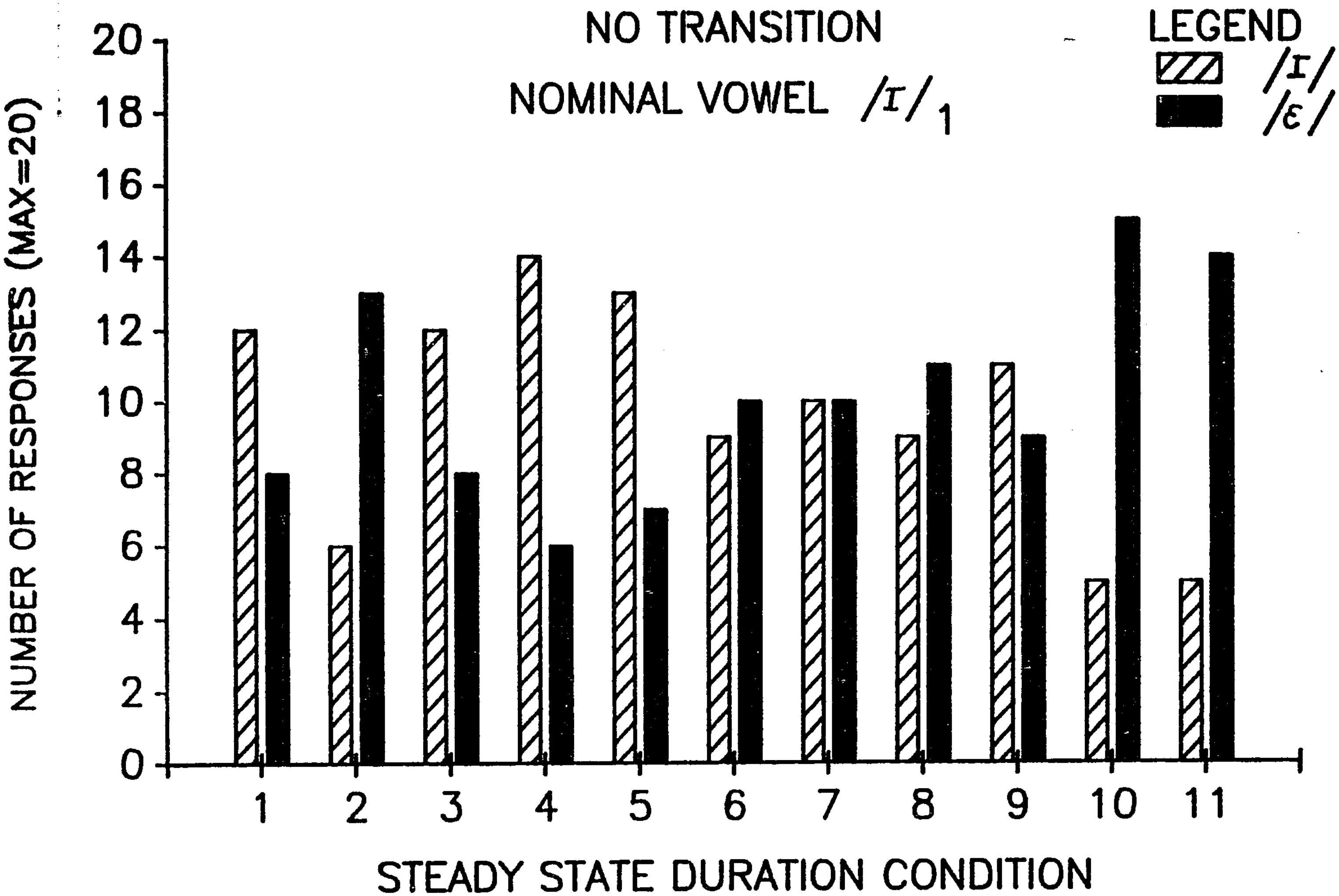

NO TRANSITION
NOMINAL VOWEL /ɪ/ 1
LEGEND
/ɪ/
/ɛ/
NUMBER OF RESPONSES (MAX=20)
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
STEADY STATE DURATION CONDITION

Figure 2. Number of responses as a function of steady state duration. The nominal vowel $/I_1/$ with an 8 ms initial transition and 80 ms final transition served as stimulus.

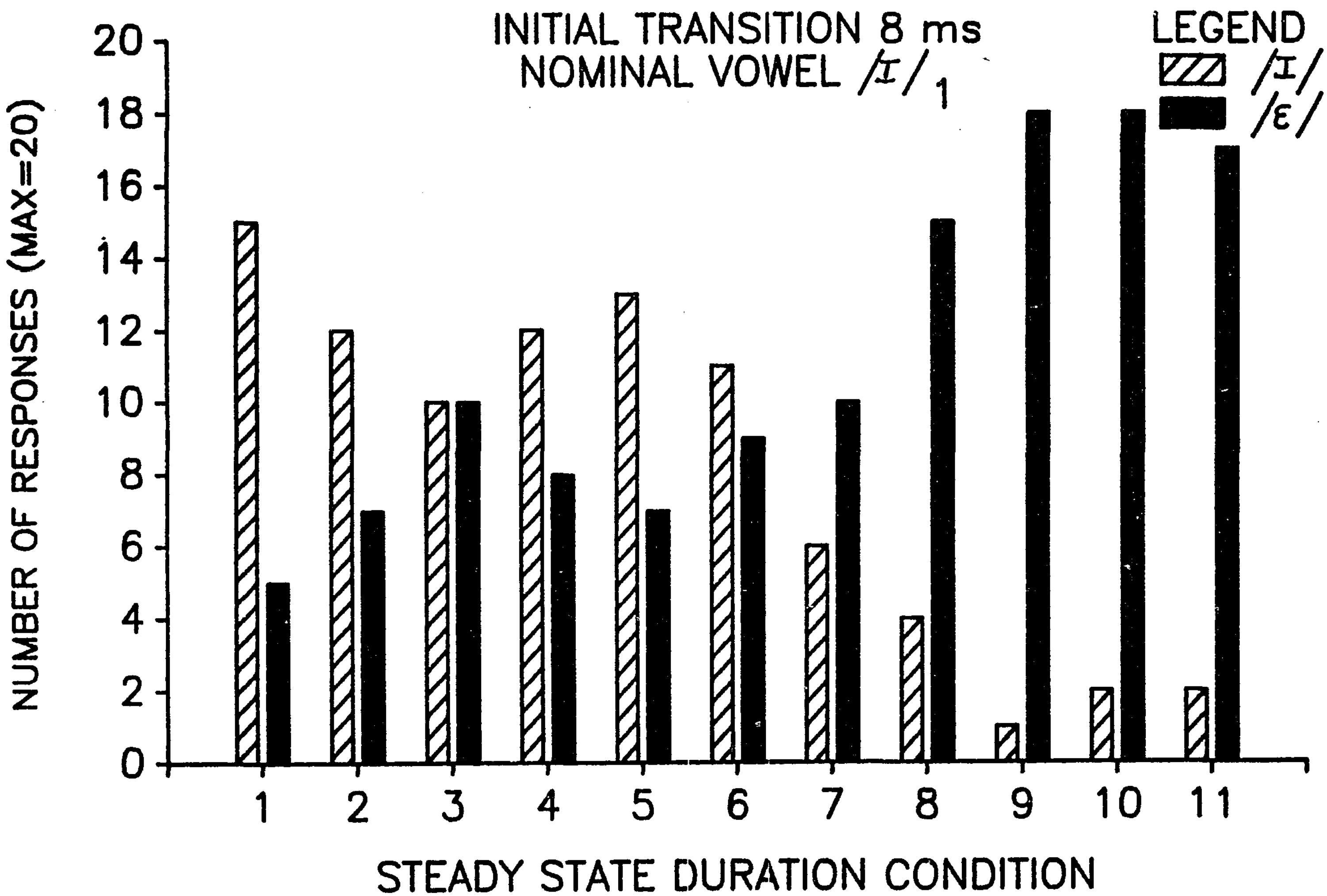

INITIAL TRANSITION 8 ms
NOMINAL VOWEL /ɪ/ 1
LEGEND
/ɪ/
/ɛ/
NUMBER OF RESPONSES (MAX=20)
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
9
10
11
STEADY STATE DURATION CONDITION

Figure 3. Number of responses as a function of steady state duration. The nominal vowel $/I_1/$ with a 56 ms initial transition and an 80 ms final transition served as stimulus.

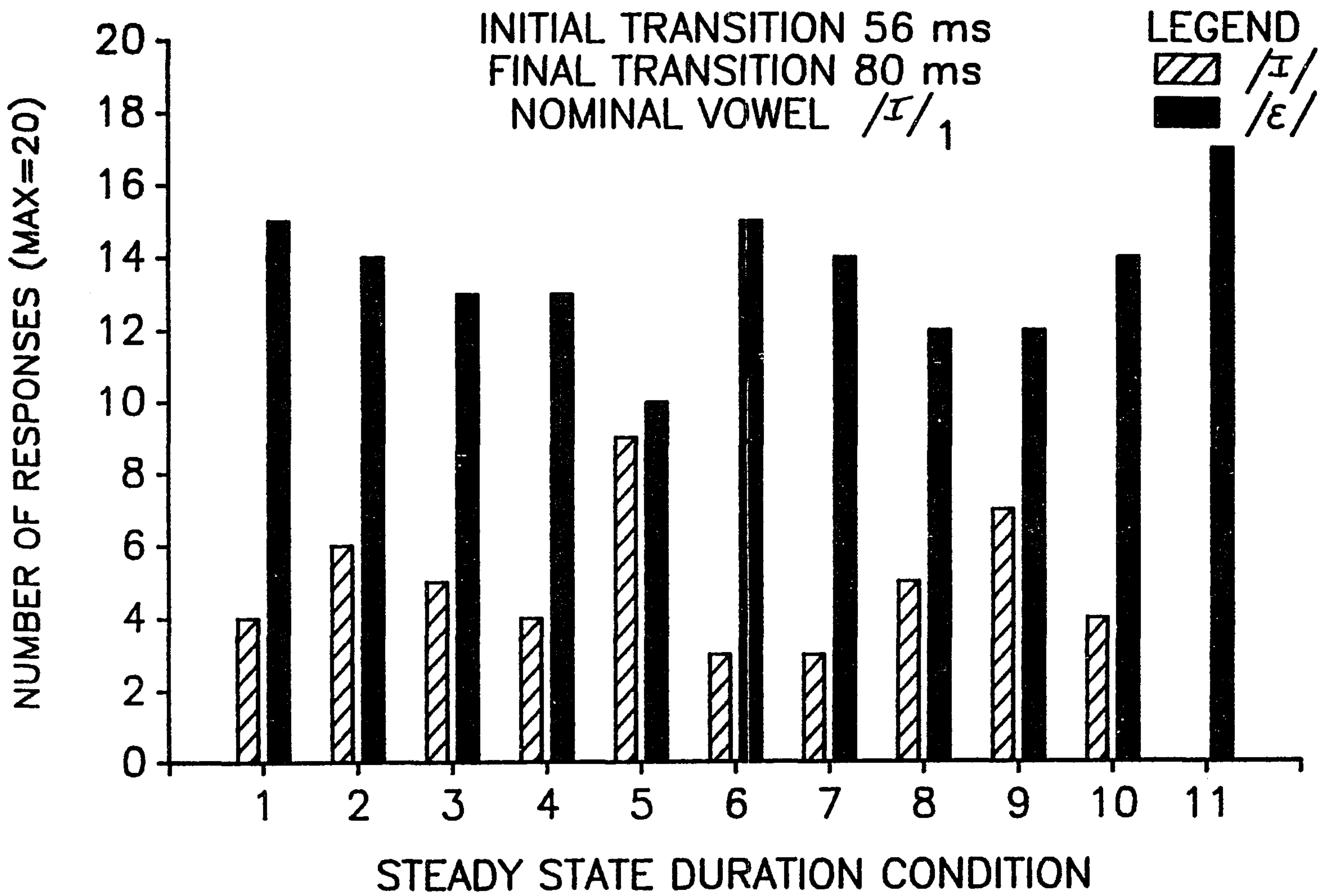
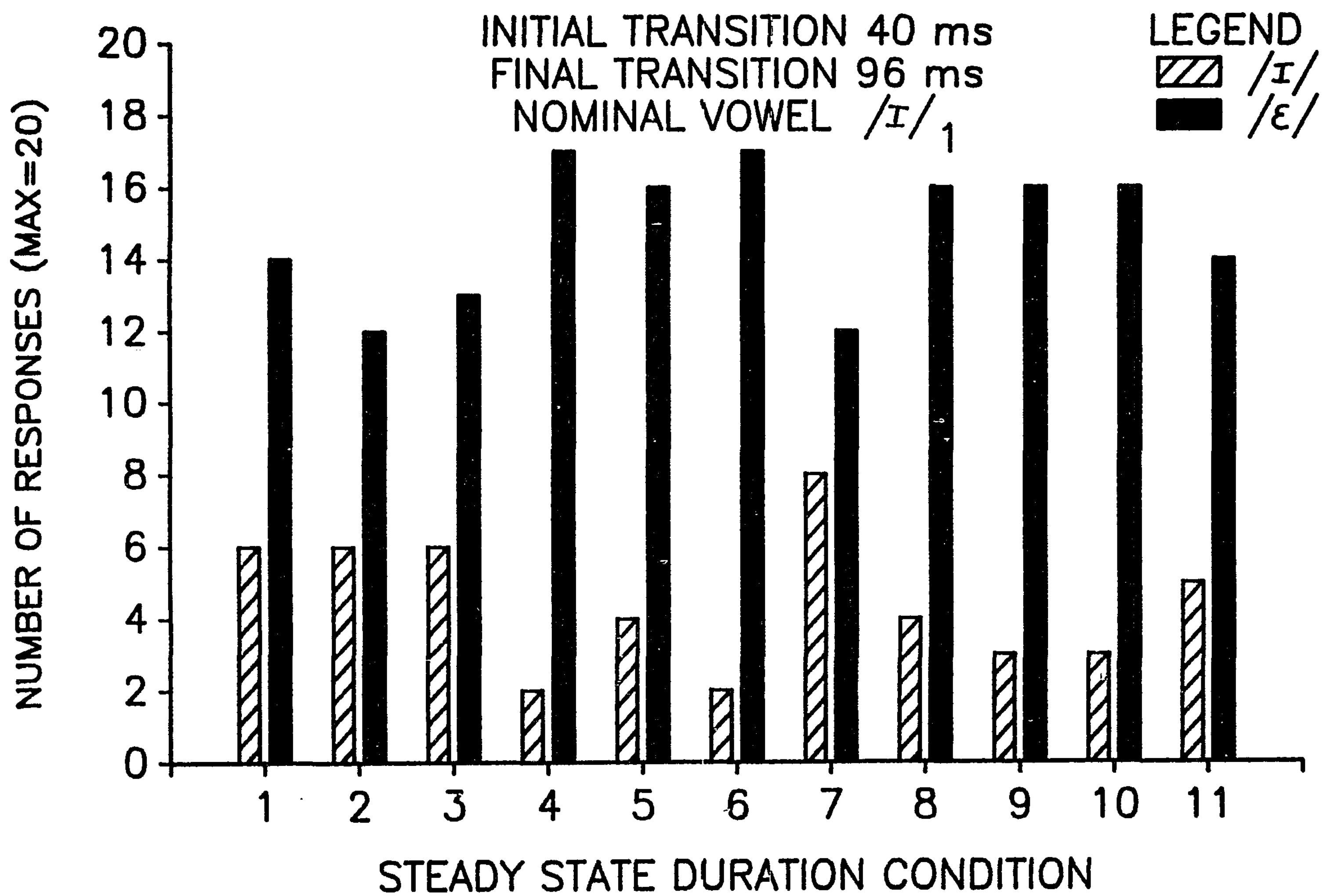

INITIAL TRANSITION 56 ms
FINAL TRANSITION 80 ms
NOMINAL VOWEL /ɪ/1
LEGEND
/ɪ/
/ε/
NUMBER OF RESPONSES (MAX=20)
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
STEADY STATE DURATION CONDITION

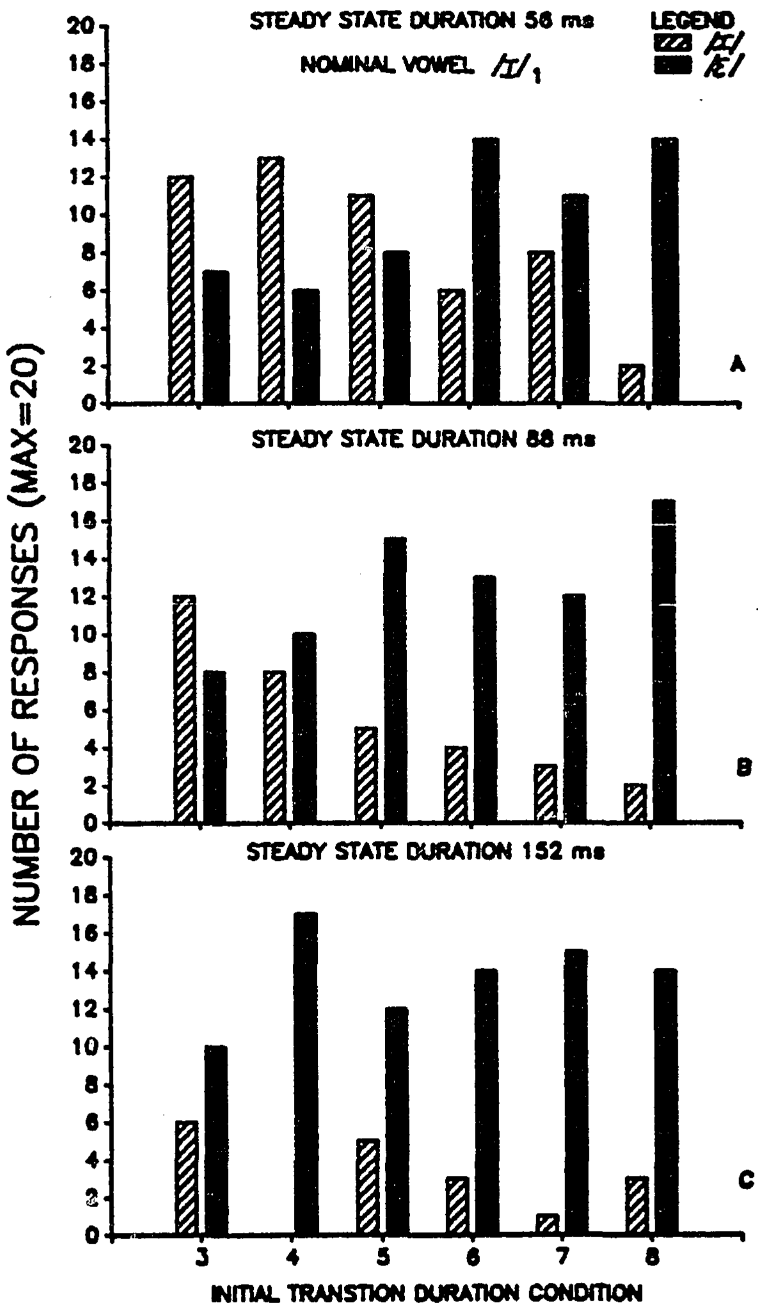
Figure 4. Number of responses as a function of steady state duration. The nominal vowel $/I_1/$ with a 40 ms initial transition and a 96 ms final transition served as stimulus.


INITIAL TRANSITION 40 ms
FINAL TRANSITION 96 ms
NOMINAL VOWEL /ɪ/ 1
LEGEND
/ɪ/
/ɛ/
NUMBER OF RESPONSES (MAX=20)
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
STEADY STATE DURATION CONDITION

Figures 2 and 4. Also, the final transition for the stimuli in Figure 4 was longer than the final transitions for the stimuli used in Figures 2 and 3. Further, the total duration of the stimuli was equal for the conditions shown in Figures 3 and 4. This effect of steady state duration appears to diminish as the initial or final transition increase in duration. Thus as can be seen in Figures 3 and 4 changes in steady state duration fail to induce the previously observed shift in labels from /I/ to /ɛ/. Similarly, in Figure 4 there is no effect of steady state duration.

2. Initial Transition Duration. It is clear from the previous discussion that steady state duration was an important clue in distinguishing /I/ from /ɛ/ for vowels with the same formant structure. After having obtained insight into the effects of steady state duration within a given transition condition, the natural question is if a similar effect is noted with changes in initial transition duration within a given steady state condition. The responses illustrated in Figures 5a-5c are used to demonstrate just that effect. As can be seen in Figure 5a, if the steady state duration is sufficiently short (56 ms), increases in the initial transition appear to yield a decrease in the number of /I/ responses. Further, as seen

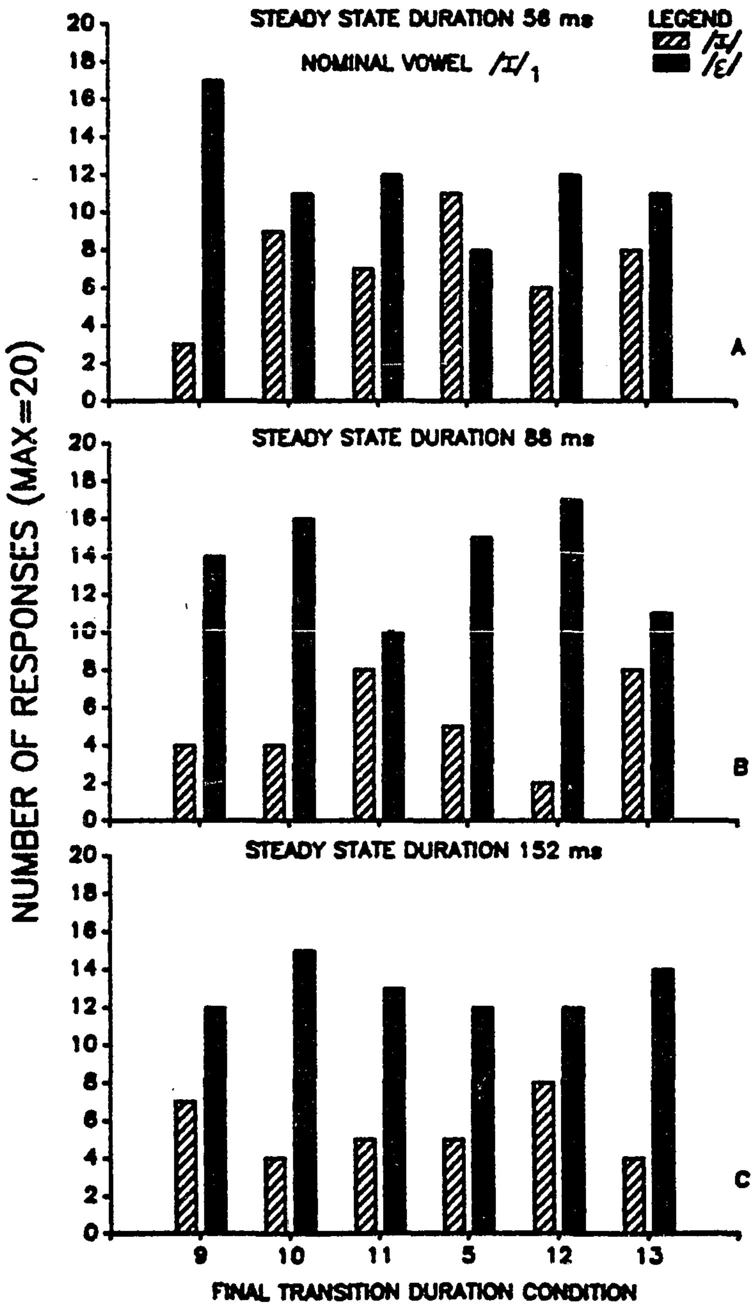
Figure 5. Number of responses as a function of initial transtition duration. A nominal vowel $/I_1/$ with a 56 ms steady state duration (Figure 5a), an 88 ms steady state (Figure 5b) and a 152 ms steady state (Figure 5c) served as stimulus.


STEADY STATE DURATION 56 ms
NOMINAL VOWEL /ɪ/1
LEGEND
/ɪ/
/ɛ/
A
STEADY STATE DURATION 88 ms
B
STEADY STATE DURATION 152 ms
C
NUMBER OF RESPONSES (MAX=20)
INITIAL TRANSITION DURATION CONDITION
3
4
5
6
7
8

in Figure 5b, showing data for 88 ms steady state duration, an increase in initial transition duration yields a decrease in the number of /I/ responses. This pattern appears to hold until the steady state duration is greater then 120 ms (Figure 5c). Thus increasing initial transition duration has an effect similar to increasing steady state duration. That is, increases in initial transition duration or steady state duration yield a decrease in the number of /I/ responses. This pattern appears to hold until the steady state duration is greater than 120 ms. This interaction limits the ability to describe the main effects of the changes in duration of only one component of the signal.

3. Final Transition Duration. As with the initial transition conditions there appears to be an interaction between the steady state duration and the final transition duration. The effect, however, is limited to much shorter steady state durations. In order to compare the effects of the initial and final transitions, Figure 6 is constructed in a parallel to Figure 5. That is, the steady state durations in corresponding panels of Figures 5 and 6 are the same. The effect of final transition duration appears to diminish if the steady state is greater than 72 ms. In other words, as the final transition duration

Figure 6. Number of responses as a function of final transition duration. A nominal vowel $/I/_1$ with a 56 ms steady state duration (Figure 6a), an 88 ms steady state (Figure 6b), and a 152 ms steady state (Figure 6c) served as stimulus.


STEADY STATE DURATION 58 ms
NOMINAL VOWEL /I/1
LEGEND
/I/
/ε/
A
STEADY STATE DURATION 88 ms
B
STEADY STATE DURATION 152 ms
C
NUMBER OF RESPONSES (MAX=20)
9
10
11
5
12
13
FINAL TRANSITION DURATION CONDITION

increases, the number of /I/ responses does not change if the steady state is greater than 72 ms. As with the initial transition conditions, if /I/ was not chosen as the response, /ɛ/ was the alternative of choice. Again, because there is an apparent interaction between the steady state and the final transition conditions a discussion of simple main effects is not appropriate.

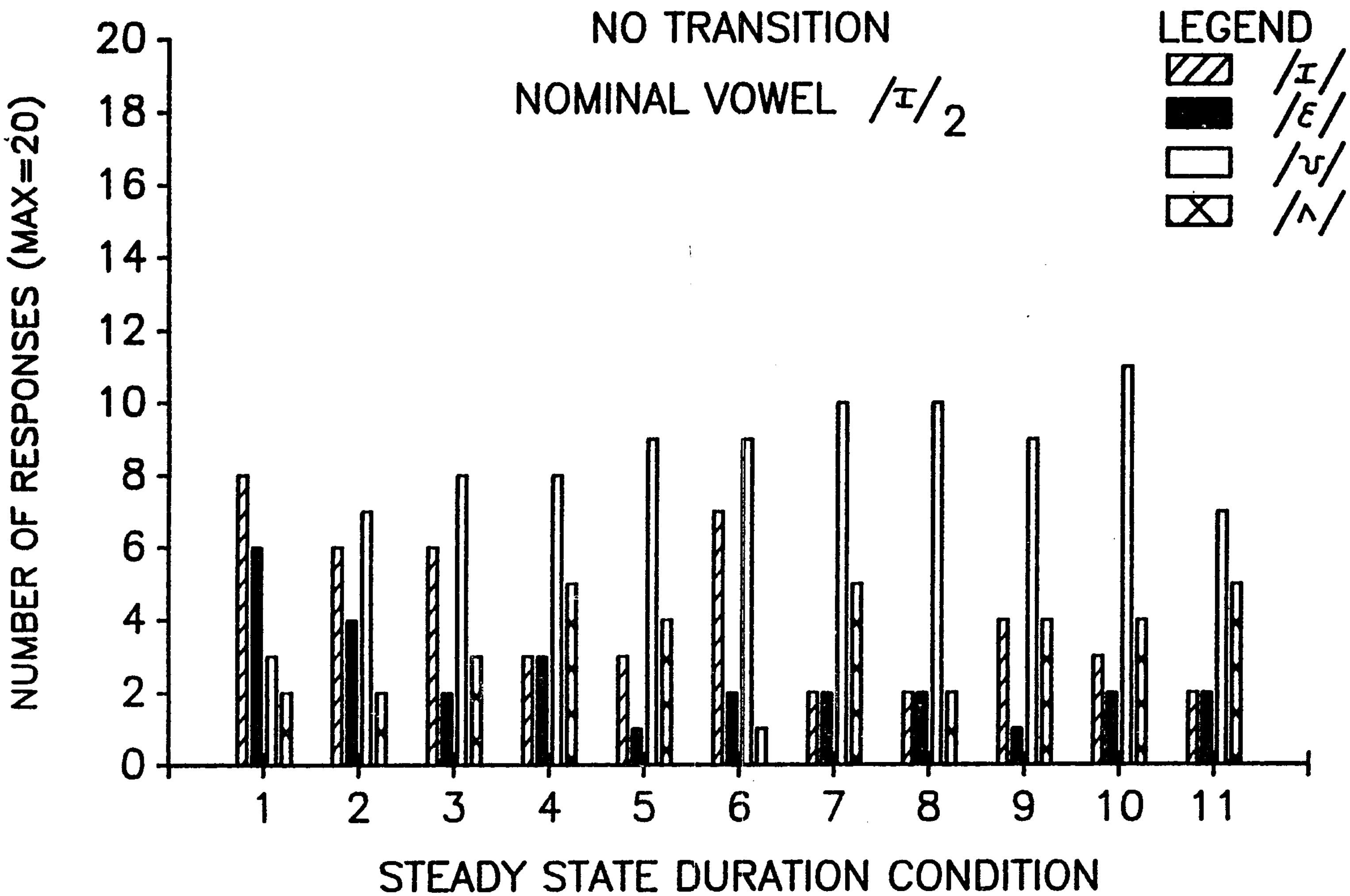
Normal Hearing Listeners--$/I/_2$

1. Steady State Duration. The number of /I/ responses for the normal hearing subjects is summarized in Table 22. As can be seen in that table, there is an effect of steady state duration in the responses to the $/I/_2$. However, the effects for this nominal vowel are somewhat more complex than for the nominal vowel $/I/_1$. Approximately half of the responses from the normal hearing subjects were /ʊ/; other responses were divided among /I,ʌ/ and occassionally /ɝ/. Figure 7 is a summary of the patterns of response for the normal hearing subjects if the stimulus consisted of steady state alone. As can be observed there are more /ʊ/ and /ʌ/ responses, and fewer /I/ and /ɛ/ responses with increases in steady state duration.

Table 22. A summary of the total number of /I/ responses by normal hearing subjects to the nominal vowel /I/$_2$ (max=20) (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	8	6	6	3	3	7	2	2	4	3	2
8	5	3	4	3	4	2	4	4	1	4	4
24	2	2	4	3	2	4	4	2	2	2	2
40	6	2	5	3	4	2	4	2	2	3	2
56	3	2	4	1	2	2	2	2	2	3	2
72	4	3	3	3	2	3	2	3	2	4	2
88	2	2	4	4	3	3	2	4	2	2	2
FTD (ms)											
32	3	3	3	4	3	2	5	3	2	2	2
48	2	4	2	3	4	4	2	4	2	2	3
64	2	3	3	3	3	3	3	3	2	2	3
80	6	2	5	3	4	2	4	2	2	2	2
96	4	2	3	3	4	2	3	4	2	2	2
112	2	2	4	3	4	1	2	2	3	3	1

Figure 7. Number of responses as a function of steady state duration. The nominal vowel $/I/_2$ without transitions served as stimulus.


NO TRANSITION
NOMINAL VOWEL /ɪ/2
LEGEND
/ɪ/
/ɛ/
/ʊ/
/ʌ/
NUMBER OF RESPONSES (MAX=20)
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
9
10
11
STEADY STATE DURATION CONDITION

2. Transition Durations. Because there was little difference in the effects of the initial and final transitions these results will be presented together. In general, with the formant structure of the nominal vowel $/I/_2$ (i.e., reduced F2) the transitions appear to have little effect. As illustrated in Figures 8 and 9, there is no effect of increasing either initial (Figure 8) or final transition duration (Figure 9). Further, when comparing Figures 8 and 9, it is apparent that the previously observed interactions between the steady state duration and the transition durations are not present.

Hearing Impaired Subjects

The differences in response patterns for the nominal vowels $/I/_1$ and $/I/_2$ that were evident for the normal hearing listeners were not evident for hearing impaired listeners. The results for the hearing impaired listeners, then, will again be presented on an individual basis, with the effects of the changes in formant frequency structure considered within the context of the various duration effects.

Figure 8. Number of /I/ responses as a function of initial transition duration for 56 ms and 200 ms steady state duration conditions. The nominal vowel $/I/_2$ served as stimulus.

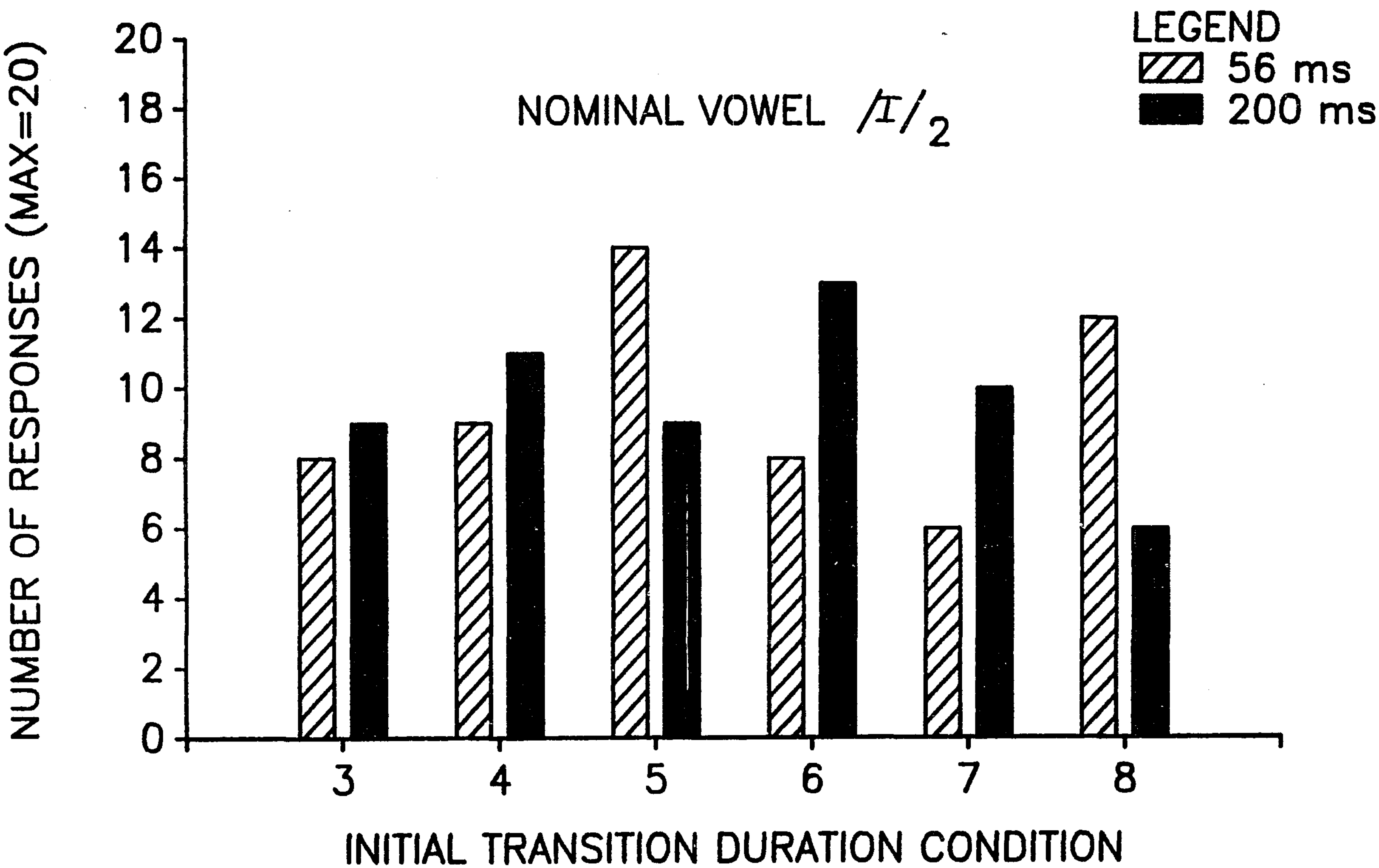
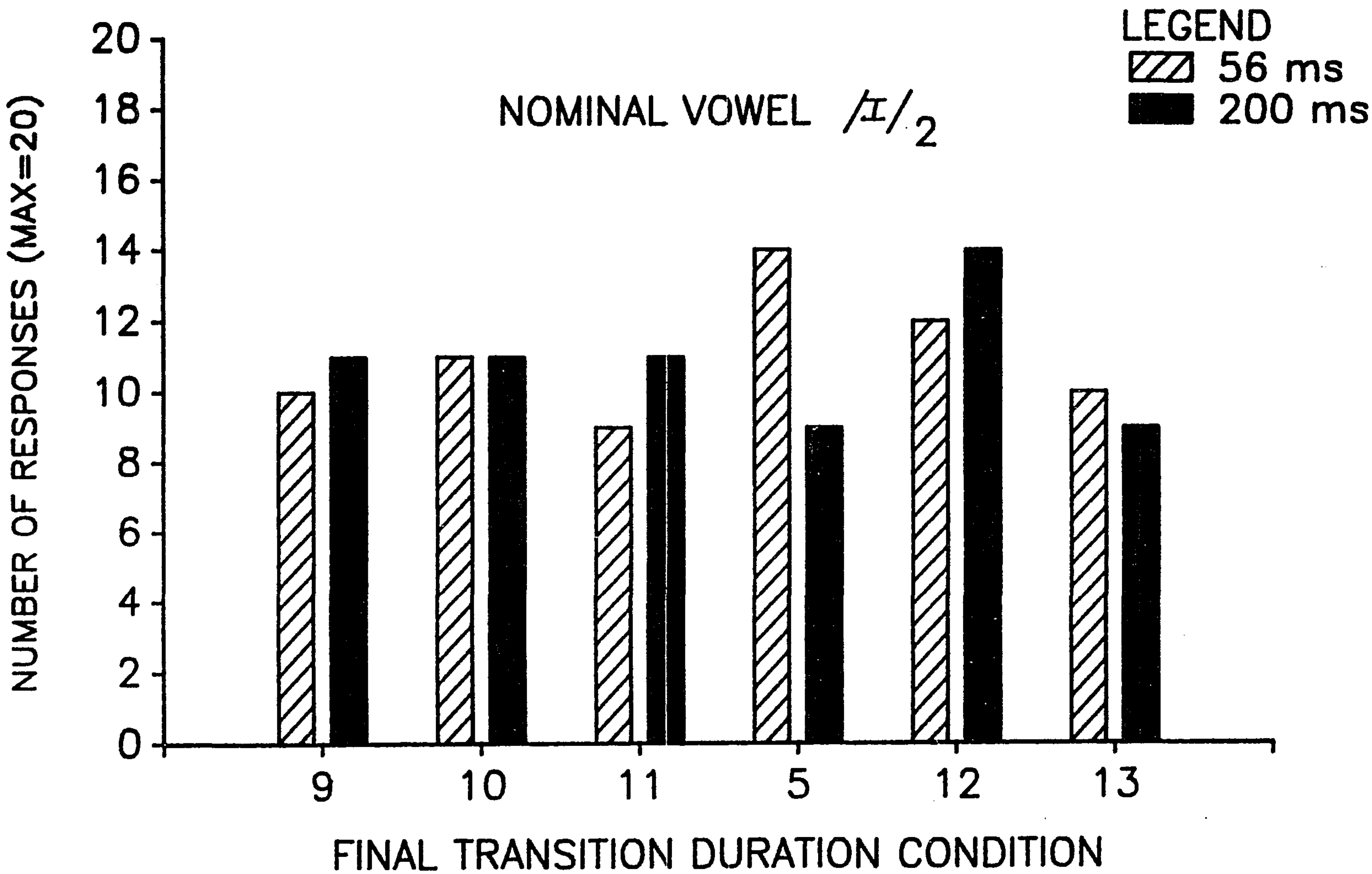

NOMINAL VOWEL /ɪ/₂
LEGEND
56 ms
200 ms
NUMBER OF RESPONSES (MAX=20)
20
18
16
14
12
10
8
6
4
2
0
3
4
5
6
7
8
INITIAL TRANSITION DURATION CONDITION

Figure 9. Number of /I/ responses as a function of final transition duration for 56 ms and 200 ms steady state duration conditions. The nominal vowel $/I/_2$ served as stimulus.


LEGEND
56 ms
200 ms
NOMINAL VOWEL /ɪ/2
NUMBER OF RESPONSES (MAX=20)
0
2
4
6
8
10
12
14
16
18
20
9
10
11
5
12
13
FINAL TRANSITION DURATION CONDITION

1. Steady State Duration. Changes in response patterns as a function of steady state duration occurred for hearing impaired subjects HI-1, HI-3, and HI-4. However, the characteristics of the patterns and the reliability of the responses were different for each subject.

The results for subject HI-1 are presented in Tables 23 and 24. This subject was somewhat erratic in her response pattern for the nominal vowel $/I/_1$. In general, with increasing steady state duration, the responses shifted from /I/ toward more neutral vowels. It should be noted that at longer steady state durations, consistent responses were not always obtained (indicated by the number of empty cells). The nominal vowel $/I/_2$ generated less erratic response pattern, but again there was a failure to obtain reliable responses at the longer duration stimuli. As with the vowel $/I/_1$, the short steady state duration stimuli generated /I/ responses.

As can be seen in the response data provided in Tables 25 ($/I/_1$) and Table 26 ($/I/_2$), subject HI-3 identified short duration stimuli as /I/. The effect of steady state duration on the identification of $/I/_1$ was different for the stimuli in which there were no transitions than for the stimuli with initial and final transitions. For the nominal vowel $/I/_1$ in the no-transition condition, the only response chosen by this listener was /I/; however, for the

Table 23. Response table for hearing impaired subject HI-1. The nominal vowel $/I/_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		I		I	ʌ					
8					ʌ						ɔ
24	I		æ		æ						
40					ɛ						u
56					ʊ	æ					ɛ
72	I		æ						ɛ		
88					ʊ	ɛ					ʌ
FTD (ms)											
32	I				ɛ				æ		
48	I		ɛ						ɔ		ɛ
64	ɛ		æ								
80					ɛ						u
96						ɛ					
112											ʊ

Table 24. Response table for hearing impaired subject HI-1. The nominal vowel $/I/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		I		I	æ			a		
8			I		æ	u			u		
24	æ				æ	I					ɛ
40	ɛ		I		æ	ɛ					
56	æ		æ			ɛ					
72	I										ɔ
88	æ				ɛ				ɛ		ʊ
FTD (ms)											
32			æ		I	ɛ			ɔ		
48			æ			æ					
64					æ	ɛ					
80	ɛ		I		æ	ɛ					
96			ɛ								ʊ
112			ɛ								ʊ

Table 25. Response table for hearing impaired subject HI-3. The nominal vowel $/I/_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		I		I				I		
8			I						ɝ		æ
24	I				ɝ				u		ɝ
40	I								ɝ		ʊ
56	I		ʊ		u	ɛ					ɝ
72			ʌ			ɝ					
88					ɔ				ɔ		
FTD (ms)											
32	ʌ		I			æ					ɛ
48	I				u	ɥ					ɛ
64	ʌ		ɝ		u	ɥ					ɝ
80	I								ɝ		ʊ
96	I		ʌ		u	ɥ					ɝ
112	ʌ				ɝ						

Table 26. Response table for hearing impaired subject HI-3. The nominal vowel $/I/_2$ served as stimulus. (Note: ITD=initial transition duration FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		ʌ			ɑ			ʊ		
8	ʌ				ɝ				ʊ		ʊ
24	ʌ					ʊ			ʊ		ʊ
40	ʌ					ɝ					ɔ
56			ʌ		ʊ	ʊ			ʊ		ʊ
72	ʊ					ʊ					ʊ
88					u	ɝ			ɝ		ʊ
FTD (ms)											
32	ʌ				ʌ	ʊ					ʊ
48	I		I		ʌ	ʊ			ʊ		ʊ
64	ʌ		ʌ		ʊ	ʊ			ʊ		ʊ
80	ʌ					ɝ					ɔ
96			ʊ		ʊ	ʌ			u		ʌ
112			ʊ		ʌ	ʊ					ʊ

stimuli with both initial and final transitions, the responses were either /u/, /ɝ/, or /ɛ/ at the longer steady state durations. For the nominal vowel $/I/_2$ on the other hand, there were no differences in response patterns for those stimuli with and without transitions. Specifically, with increasing steady state duration the typical response was /ʊ/ in both the no-transition condition and in all the transition conditions.

Subject HI-4 also consistently identified the short steady state duration vowels as /I/. The response data for this subject are provided in Table 27 ($/I/_1$) and Table 28 ($/I/_2$). As can be seen in Table 27, the effect of increasing steady state duration was a shift in labels from /I/ for short duration stimuli to /ɛ/ for long duration stimuli. This effect, however, was limited to short initial transition durations (i.e., $\leq$ 40 ms).

Response tables for subject HI-6 are provided in Tables 29 and 30. This subject consistently chose /ʌ/ as the primary response. In general, the effect of steady state duration was minimal in generating changes in response patterns for $/I/_1$ and $/I/_2$. The responses from subject HI-5 (Tables 31 and 32) were similar to the responses for subject HI-6 in terms of consistency. However, the primary response for subject HI-5 was /ɛ/ as compared to the primary response of /ʌ/ for subject HI-6.

Table 27. Response table for hearing impaired subject HI-4. The nominal vowel $/I_1/$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		ɛ		I	ɛ			ɛ		ɛ
8	I		ɛ		I	ɛ			ɛ		ɛ
24	I		ɛ		ɛ	I			ɛ		ɛ
40	I		ɛ		ɛ	ɛ			ɛ		ɛ
56	ɛ		I		ɛ	I			ɛ		ɛ
72	ɛ		ɛ		I	ɛ			ɛ		ɛ
88	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
FTD (ms)											
32	I		I		ɛ	I			ɛ		ɛ
48	I		ɛ		ɛ	ɛ			ɛ		ɛ
64	ɛ		ɛ		ɛ	I			ɛ		ɛ
80	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
96	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
112	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ

Table 28. Response table for hearing impaired subject HI-4. The nominal vowel $/I/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		I		ɛ	I			I		I
8	I		I		I	ɛ			ɛ		I
24	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
40	I		ɛ		ɛ	I			ɛ		ɛ
56	I		I		ɛ	ɛ			ɛ		ɛ
72	I		ɛ		I	ɛ			ɛ		ɛ
88	ɛ		I		I	I			ɛ		I
FTD (ms)											
32	ɛ		ɛ		I	I			ɛ		I
48	I		I		I	ɛ			ɛ		ɛ
64	I		ɛ		ɛ	I			I		I
80	I		ɛ		ɛ	I			ɛ		ɛ
96	ɛ		I		ɛ	ɛ			I		I
112	I		ɛ		I	ɛ			I		I

Table 29. Response table for hearing impaired subject HI-6. The nominal vowel $/I/_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	æ		I		æ	æ			æ		æ
8	æ		æ		ε	ε			æ		ɝ
24			ε		æ	æ			æ		ɝ
40	æ		æ		æ	æ			æ		æ
56	æ		æ		æ	æ			æ		æ
72	æ		æ		æ	æ			æ		æ
88	æ		æ		æ	æ			æ		æ
FTD (ms)											
32	æ		æ		æ	æ			æ		æ
48	æ		ε		æ	æ			æ		æ
64	æ		æ		æ	æ			ε		ε
80	æ		æ		æ	æ			æ		æ
96	ε		ε		æ	ε			æ		æ
112	æ		æ		æ	æ			æ		

Table 30. Response table for hearing impaired subject HI-6. The nominal vowel /I/$_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		æ		æ	æ			æ		æ
8	æ		æ		æ	æ			ɛ		æ
24	I		æ		æ	æ			æ		æ
40	æ		æ		æ	æ			æ		ʊ
56	æ		æ		æ	ɝ			æ		æ
72	æ		æ		æ	æ			æ		
88	æ		æ		æ	æ			æ		æ
FTD (ms)											
32	ʌ		æ		æ	ɛ			æ		æ
48	ɛ		æ		æ	æ			æ		æ
64			æ		æ	ɛ			æ		æ
80	æ		æ		æ	æ			æ		ʊ
96	æ		æ		æ	æ			æ		æ
112	æ		æ		æ	æ			æ		æ

Table 31. Response table for hearing impaired subject HI-5. The nominal vowel $/I_1/$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ɛ		ɛ		ɛ	ɛ			æ		ɛ
8	ɛ		ɛ		ɛ	ɛ			ɛ		æ
24	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
40	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
56	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
72	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
88	ɛ		ɛ		ʌ	ɛ			ɛ		ɛ
FTD (ms)											
32	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
48	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
64	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
80	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
96	ɛ		ɛ		ɛ	ɛ			ɛ		ɛ
112	ɛ		ɛ		ɛ	ɛ			ɛ		

Table 32. Response table for hearing impaired subject HI-5. The nominal vowel $/I/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ε				ε	ε			æ		ε
8	ε		æ		ε	ε			ε		ε
24	æ		ε		ε	ε			ε		ε
40	ε		ε		ε	ε			ε		ε
56	ε		ε		ε	ε			ε		ε
72	ε		ε		ε	ε			ε		ε
88	ε		ε		ε				ε		ε
FTD (ms)											
32	ε		æ		ε	ε			ε		ε
48	ε		ε		ε	ε			ε		ε
64	ε		ε		ε	ε			ε		ε
80	ε		ε		ε	ε			ε		
96	ε		ε		ε	ε			ε		
112	ε		ε		ε	ε			ʌ		ε

Also, the effect of steady state duration was minimal in generating changes in response patterns for either version of the nominal vowel /I/.

Tables 33 and 34 provide summaries of the response patterns for subject HI-2. In general this subject tended to select /ɝ/ as his primary response to the nominal vowel $/I/_1$ if the total duration was less than 320 ms. However, his responses to the nominal vowel $/I/_2$ were typically /ɝ/ independent of total duration.

Tables 35 and 36 are the cummulative results for the normal hearing subjects and are provided for the sake of comparison. In general, subjects HI-1 and HI-4 responded similarly to the normal hearing subjects for short steady state duration stimuli (i.e., $\leq$ 88 ms). The remaining subjects were different in their response alternatives, the pattern of such responses, and the reliability with which the stimuli were labeled.

2. Transition Duration. The effect of transition duration is highly diverse both within and between subjects. Therefore, the various effects of transition will be considered together for each individual subject.

The response patterns for Subject HI-1 (Tables 23 and 24) indicated that changes in the initial transition generated different effects than changes in the final transition. The most obvious results are the increased

Table 33. Response table for hearing impaired subject HI-2. The nominal vowel $/I_1/$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ɝ		ɝ		ɛ	ɝ			ɝ		ɛ
8	ɝ		ɝ		ɝ	ɛ			ɝ		ɛ
24	ɝ		ɛ		ɝ	ɝ			ɛ		ɛ
40	ʌ		ɝ		ʌ	ɛ			ɛ		ɛ
56	ɝ		ɝ			ʌ			ʌ		ʌ
72	ɝ				ɛ	ʌ			ʌ		
88	ʌ		ɝ		ɝ				ɛ		ɛ
FTD (ms)											
32	ɝ		ɝ		ɝ	ɝ			ɛ		ɝ
48	ɝ		ɛ		ɝ	ɝ			ʌ		
64	ɝ		ɛ		ɝ	ɛ					
80	ʌ		ɝ		ʌ	ɛ			ɛ		ɛ
96	ɝ				ɛ	ɛ			ɛ		ɛ
112	ɛ		ɛ		æ	ɝ			ɛ		æ

Table 34. Response table for hearing impaired subject HI-2. The nominal vowel $/I/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ɛ		ɝ		ɝ	ɝ			ɝ		ɛ
8	ɝ		ɝ		ɝ				ɝ		ɛ
24	ɝ		ɝ		ɝ	ɝ					ɝ
40	ʌ		ʌ		ʌ	ʌ			ʌ		
56	ʌ		ɝ						ʌ		ɛ
72	ɝ		ɝ		ɝ	ɝ			ɛ		ɛ
88	ɛ		ɛ		ʌ	ɝ			ɝ		
FTD (ms)											
32			ɛ			ɝ			ɝ		ʌ
48	ɝ				ʌ	ɛ			ɛ		ɝ
64	ɝ		ɛ			ɝ			ʌ		ɛ
80	ʌ		ʌ		ʌ	ʌ			ʌ		
96	ɝ		ɝ		ʌ				ʌ		ɝ
112	ɝ		ɝ			ɛ			ɛ		ɛ

Table 35. Response table for normal hearing subjects. The nominal vowel $/I/_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0		ɛ			I	I				ɛ	ɛ
8	I				I			ɛ	ɛ	ɛ	ɛ
24	ɛ	I	I		ɛ		ɛ		ɛ		ɛ
40	I			ɛ	ɛ			ɛ	ɛ		ɛ
56	ɛ	ɛ	ɛ	ɛ		ɛ	ɛ			ɛ	ɛ
72			ɛ			ɛ	ɛ	ɛ			ɛ
88		ɛ		ɛ	ɛ	ɛ	ɛ	ɛ		ɛ	ɛ
FTD (ms)											
32		ɛ		ɛ	ɛ			ɛ	ɛ	ɛ	ɛ
48			I	ɛ			ɛ			ɛ	ɛ
64			I		I	ɛ	ɛ	ɛ	ɛ		ɛ
80	I			ɛ	ɛ			ɛ	ɛ		ɛ
96	ɛ		ɛ	ɛ	ɛ	ɛ		ɛ	ɛ	ɛ	ɛ
112			ɛ		ɛ	ɛ	ɛ	ɛ	ɛ	ɛ	ɛ

Table 36. Response table for normal hearing subjects. The nominal vowel $/I/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0											
8											
24											
40											ɝ
56		ɝ									
72									ɝ		
88					ɝ						
FTD (ms)											
32											
48											
64											
80	ɝ										
96						ɝ			ɝ		ɝ
112											

number of conditions in which reliable (greater than 65% identification rate) responses could not be obtained. For the nominal vowel $/I/_1$ (Table 23), there were equal numbers of initial transition and final transition conditions in which reliable responses could not be obtained. In contrast, for the nominal vowel $/I/_2$ (Table 24), there were more empty cells for the longer final transition duration conditions than for the initial transition duration conditions. Finally, with short steady state durations, increasing the duration of either transition duration generated a response pattern in which the longer transition stimuli were primarily identified either as /ɛ/ or /ɚ/. For longer steady state durations and longer duration transitions, the response choice was /ʊ/ or /ɔ/.

Subject HI-2 used a somewhat more restricted response set than did HI-1. As seen in Tables 33 and 34, there does not appear to be a systematic effect of increasing either initial or final transition duration. Yet, as with HI-1, the addition of transitions caused shifts in the response patterns. Specifically, if the transition duration conditions were such that the initial transition was 56 ms and the final transition was 100 ms, this listener reliably chose /ʌ/ as the response for the nominal $/I/_2$ vowels. If the initial transitions were longer than 56 ms and the final transitions were longer than 100 ms, the response patterns became more systematic. In general, with longer transitions and longer steady state durations there was a greater number of /ʌ/ and /ɛ/ responses while the number of /ɝ/ responses decreased.

Short duration steady state nominal $/I/_1$ and $/I/_2$ vowels were identified as /I/ by subject HI-3. As can be seen in Tables 25 ($/I/_1$) and 26 ($/I/_2$) the responses do not appear to be systematic. However in Table 26 there is one common trend: For stimuli with steady state durations of 104 ms or longer and with final transitions less than 80 ms, this subject labeled the stimuli as /ʊ/. This same label was applied to stimuli with steady state durations of 104 ms or less and with final transition durations exceeding 80 ms. In other words, it is assumed that because the label did not change, the final transition duration has little effect if the transition is short and the steady state duration is long. The final transition also has little effect if the steady state is short and the final transition is long. This systematicity does not appear in Table 25. That is, there is an apparent lack of systematic behavior with changes in transition duration for $/I/_1$ stimuli.

The ability to identify trends in the response tables for subject HI-3 is limited because of the large number of empty cells. In other words, the stimuli failed to elicit reliable responses from this subject. This was a particular problem for the responses summarized in Table 25.

Subjects HI-4, HI-5, and HI-6 were similar in some aspects of their response behavior. These subjects were far less erratic in their responses than the other hearing impaired listeners. Also, there were very few cases in which the stimuli failed to elicit reliable responses from them.

While there were a few exceptions, changes in the initial or final transitions failed to elicit shifts in response patterns for subject HI-6 (Tables 29 and 30). The primary response for this subject was /ɝ/. This general trend is seen for both nominal vowels $/I/_1$ and $/I/_2$, indicating that the shifts in formant frequency structure did little to change the response patterns for this subject.

Subject HI-4 also used a limited response set in responding to the nominal vowels $/I/_1$ (Table 27) and $/I/_2$ (Table 28). In contrast to subject HI-6, this subject used /I/ or /ɛ/ as the primary response alternatives. The effect of transition duration was different for the nominal vowels $/I/_1$ and $/I/_2$. For the $/I/_1$ tokens, this subject's response pattern did not change with increasing initial transition if the steady state duration was 200 ms or longer. For the shorter steady state durations, the effect of increasing either the inital or final transition duration was to shift the responses from /I/ to /ɛ/. However, the responses to the nominal vowel $/I/_2$ indicated that if the steady state duration was 200 ms or greater and the final transition was long (i.e., $\geq$ 96 ms) the response was /I/. While a clear trend is not apparent, /I/ was the response for 10 of 12 stimuli with the longest initial and final transition durations.

Finally, the response pattern for subject HI-5 (Tables 31 and 32) was unaffected by changes in intial or final transition durations. There were also little, if any, differences between the response patterns for the nominal vowels $/I/_1$ or $/I/_2$.

In summary, each subject displayed idiosyncratic behavior with respect to the effect of transition duration on the response patterns. Subjects HI-4, HI-5, and HI-6 were more systematic in their responses than subjects HI-1, HI-2 or HI-3. However, none of the subjects were the same in their response patterns; nor were they similar to the normal hearing subjects (Tables 35 and 36). Further, only subjects HI-4 and HI-5 used the same response set as the normal hearing subjects. In spite of the similarity in response set between these two subjects and the normal hearing subjects, there were clear differences in the response patterns.

Nominal Vowels $/\varepsilon/_1$ and $/\varepsilon/_2$

Normal Hearing Subjects--$/\varepsilon/_1$

As with nominal vowels $/I/_1$ and $/I/_2$, response patterns to the nominal vowels $/\varepsilon/_1$ and $/\varepsilon/_2$ diverged with the formant structure of the vowel. Thus, the responses will be reported separately for the nominal vowel $/\varepsilon/_1$ and the nominal vowel $/\varepsilon/_2$. The results for the nominal vowel $/\varepsilon/_1$ with a formant structure of F1=580 Hz, F2=1880 Hz, and F3=2570 Hz will be presented first; the results for the nominal vowel $/\varepsilon/_2$ with formant structure F1=530 Hz, F2=1690 Hz, and F3=2690 Hz formant structure will follow.

1. Steady State Duration. The total number of $/\varepsilon/$ responses for the nominal vowel $/\varepsilon/_1$ for all normal hearing subjects for each steady-state by transition-duration condition is presented in Table 37. Similar to the steady state results for the nominal vowel $/I/_1$, the results for the normal hearing subjects for the nominal vowel $/\varepsilon/_1$ indicated that there is a shift in the perceived vowel. As can be seen in Figure 10, there is a decrease in the number

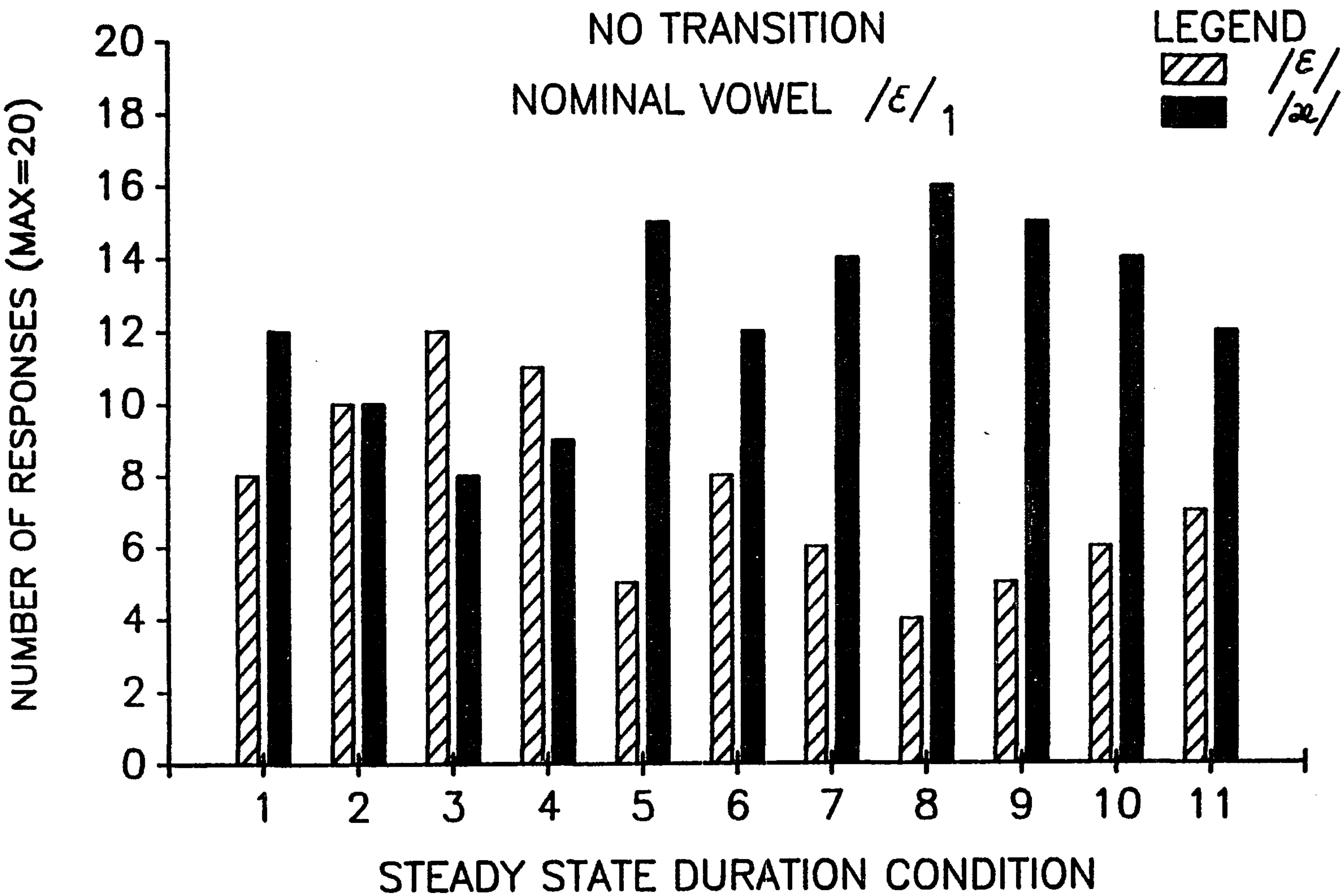
Table 37. A summary of the total number of /ɛ/ responses by normal hearing subjects to the nominal vowel /ɛ/[1] (max=20) (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	8	10	12	11	5	8	6	4	5	6	7
8	13	8	4	3	2	3	1	1	1	0	2
24	4	5	2	2	0	0	1	0	0	2	1
40	2	3	1	2	0	0	0	5	1	0	0
56	0	0	2	1	0	2	0	0	0	1	0
72	0	0	1	0	4	0	0	0	1	1	0
88	6	0	0	0	0	0	0	0	1	1	0
104	0	0	0	0	0	0	0	1	0	1	0
FTD (ms)											
52	3	2	0	2	0	0	1	0	0	1	0
68	1	5	1	2	0	0	1	1	1	1	0
84	0	0	0	3	0	1	1	1	0	0	0
100	0	0	2	1	0	2	0	0	0	1	0
116	0	1	0	1	1	1	0	0	1	0	0
132	0	2	3	1	0	1	0	2	1	1	0

of /ɛ/ response as a function of steady state duration. As depicted in Figure 10, the number of /ɛ/ responses decreases with a concomitant increase in the number of /æ/ responses. The effect of steady state duration is only apparent for the no transition and short initial transition conditions (i.e., 16 ms). The results for the short initial transition condition are depicted in Figure 11. It is apparent from that figure that there is a slight effect of steady state duration; but the effect is limited to short steady state stimuli.

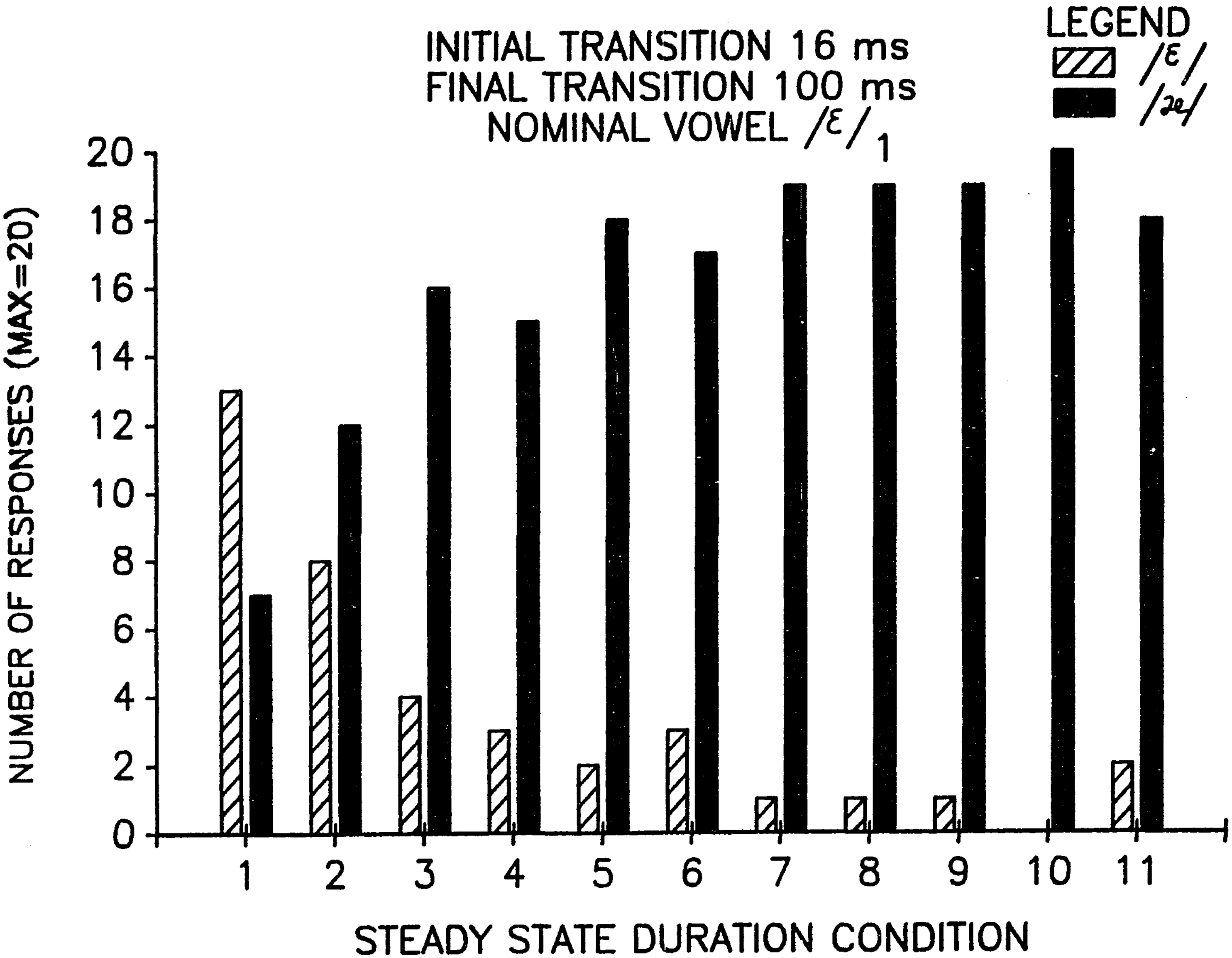
2. Initial Transition Duration. Changes in the length of the initial transition appear to have a weak effect if the steady state duration is short. For example, the effects of initial transition duration on the response pattern are presented in Figures 12a-12c. The effects were different depending on the steady state duration, as seen by comparing the panels in Figure 12. That is, a weak effect is present for steady states of 56 ms (Figure 12a) and 88 ms (Figure 12b). The effect, however, was not present if the steady state duration was 152 ms (Figure 12c).

Figure 10. Number of responses as a function of steady state duration. The nominal vowel $/\varepsilon/_1$ without transtions served as stimulus.



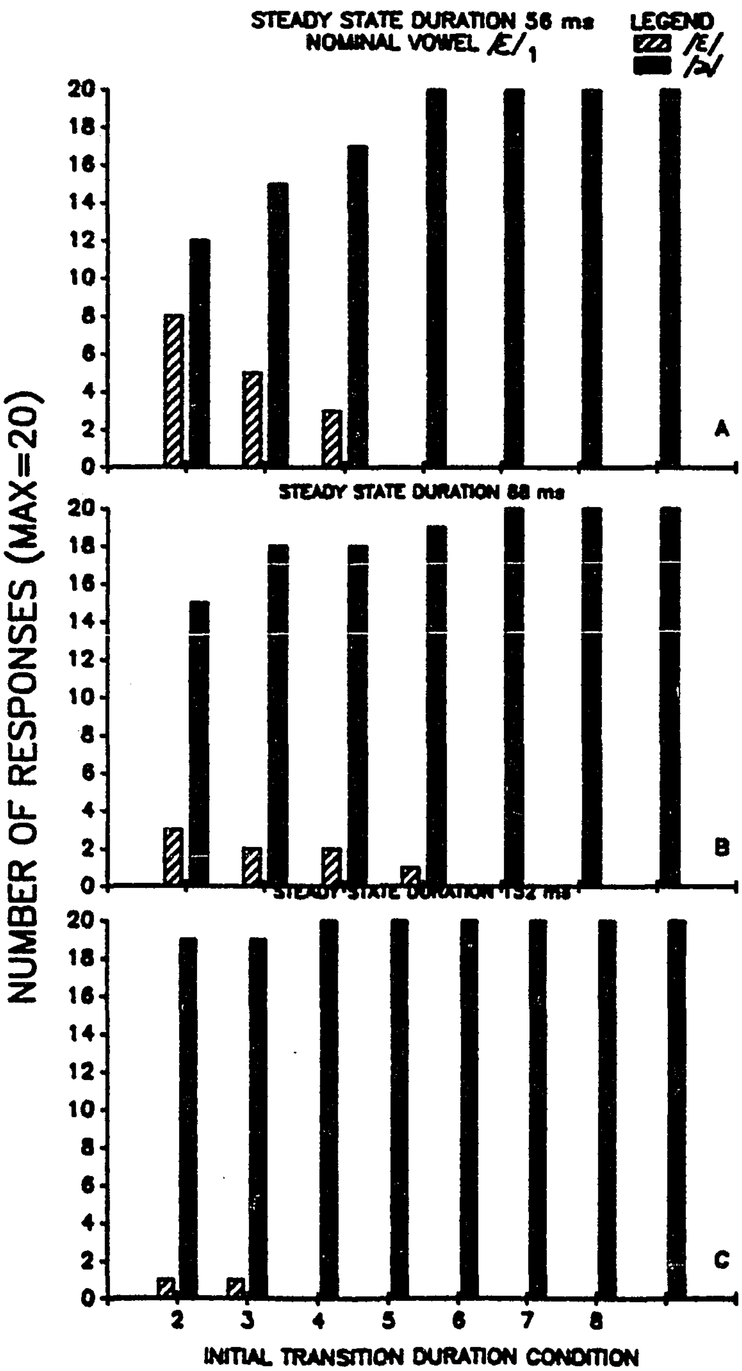
NO TRANSITION
NOMINAL VOWEL /ɛ/ 1
LEGEND
/ɛ/
/æ/
NUMBER OF RESPONSES (MAX=20)
20
18
16
14
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11
STEADY STATE DURATION CONDITION

Figure 11. Number of responses as a function of steady state duration. The nominal vowel $/\varepsilon_1/$ with a 16 ms initial transition and a 100 ms final transition served as stimulus.



INITIAL TRANSITION 16 ms
FINAL TRANSITION 100 ms
NOMINAL VOWEL /ε/
1
LEGEND
/ε/
/æ/
NUMBER OF RESPONSES (MAX=20)
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
9
10
11
STEADY STATE DURATION CONDITION

Figure 12. Number of responses as a function of initial transition duration. A nominal vowel $/\varepsilon/_1$ with a 56 ms steady state duration (Figure 12a), an 88 ms steady state duration (Figure 12b), and a 152 ms steady state duration (Figure 12c) served as stimulus.


STEADY STATE DURATION 56 ms
NOMINAL VOWEL /E/ 1
LEGEND
/E/
/ʌ/
A
STEADY STATE DURATION 88 ms
B
C
NUMBER OF RESPONSES (MAX=20)
INITIAL TRANSITION DURATION CONDITION

3. Final Transition Duration. As can be seen in the lower half of Table 37, changes in the final transition duration do not appear to contribute to any shifts in the labels assigned to $/\varepsilon/_1$. This lack of perceptual shift may be related to ceiling effects as the listeners consistently labeled these stimuli /æ/.

Normal Hearing Listeners--$/\varepsilon/_2$

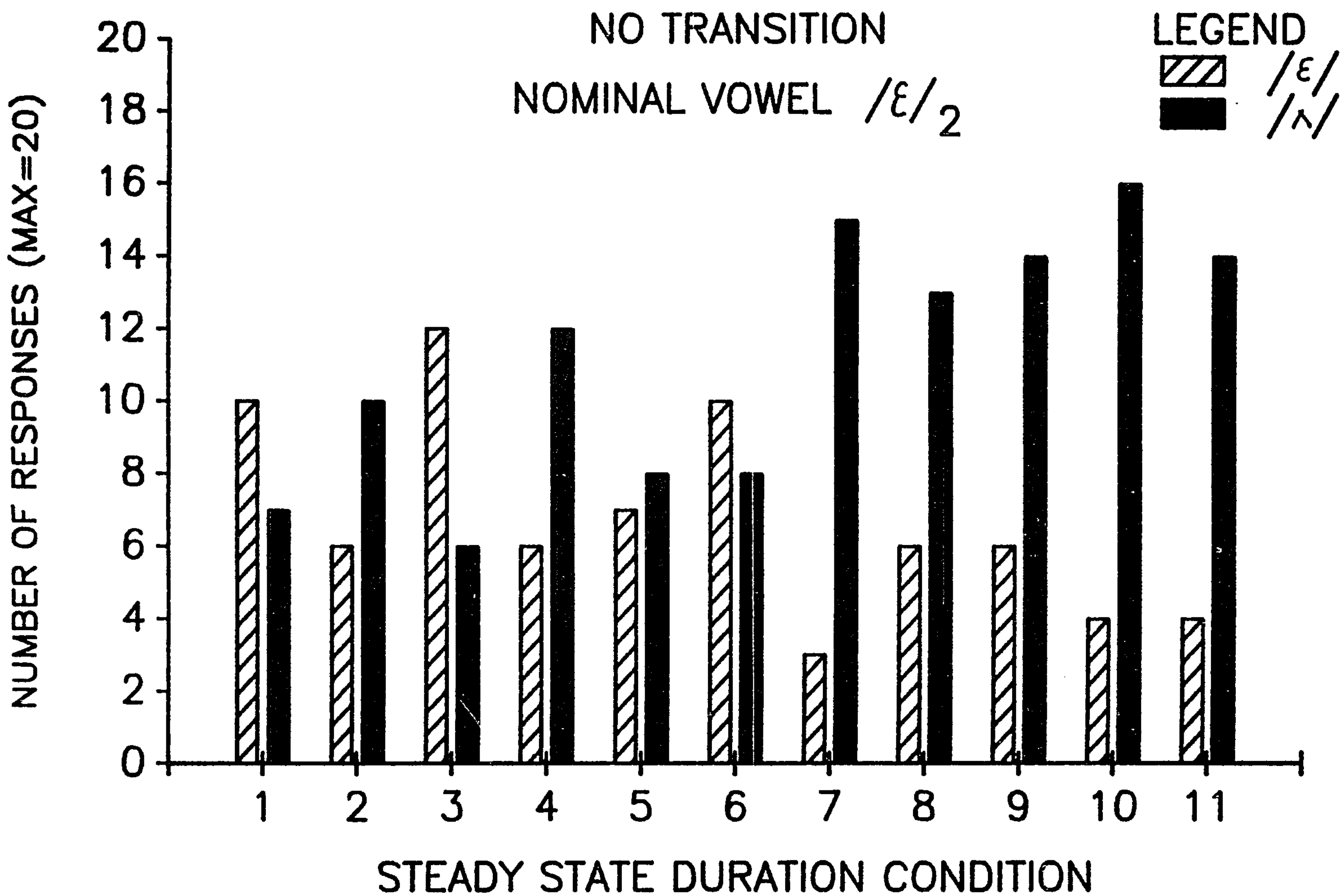
1. Steady State Duration. The effect of steady state duration on the identification of the nominal vowel $/\varepsilon/_2$ can be seen in Table 38. As steady state duration increases, the number of /ɛ/ responses decreases. As can be observed in Figure 13, the previously observed decrease in the number of /ɛ/ responses was accompanied by increases in the number of /ʌ/ responses. For this vowel, as with $/\varepsilon/_1$, there was a shift in the labels assigned for those stimuli in which the initial and final transitions were absent.

2. Transition Duration. Because there is little, if any, difference in response patterns for the initial and final transition duration conditions, the results will be considered together. In general, the effects of lengthening transitions for this stimulus was weak, yet

Table 38. A summary of the total number of /ɛ/ responses by normal hearing subjects to the nominal vowel $/\varepsilon/_2$ (max=20) (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	10	6	12	6	7	10	3	6	6	4	4
8	5	2	5	4	5	6	4	3	4	5	5
24	2	3	4	2	4	3	4	3	5	7	4
40	7	2	3	6	3	5	6	3	5	2	3
56	2	4	2	3	6	3	4	4	2	4	5
72	4	2	4	3	3	5	4	2	3	5	3
88	2	4	2	3	5	2	6	3	3	3	7
104	4	4	5	2	3	5	2	5	5	3	3
FTD (ms)											
52	4	5	7	3	4	3	5	4	3	4	5
68	4	2	2	4	4	4	4	3	4	3	4
84	4	2	2	2	3	7	5	2	4	3	5
100	2	4	2	3	6	3	4	4	2	4	5
116	2	4	5	4	2	4	5	2	2	6	2
132	4	3	4	2	4	4	2	3	4	5	5

Figure 13. Number of responses as a function of steady state duration. The nominal vowel $/\varepsilon/_2$ without transitions served as stimulus.

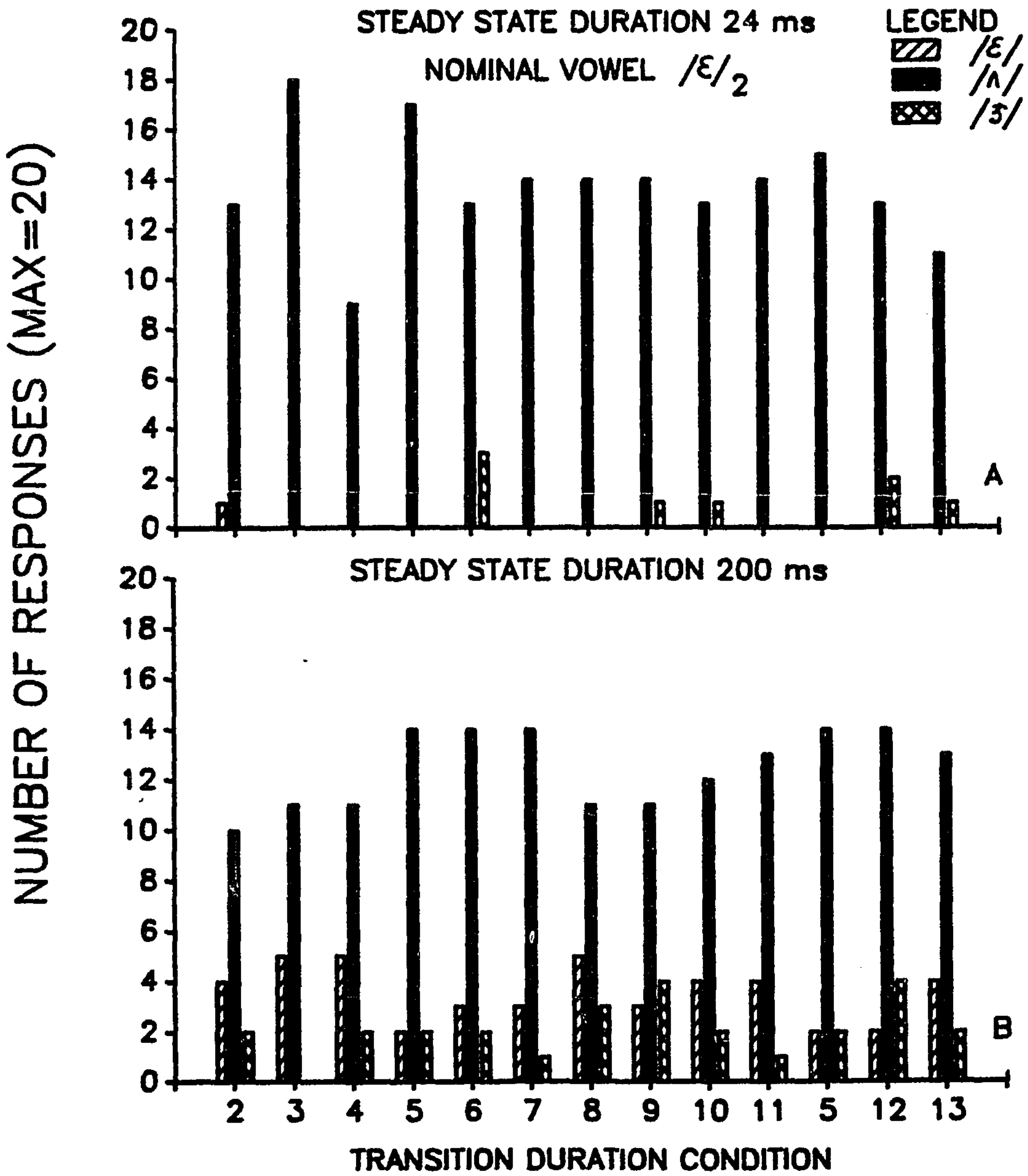

NO TRANSITION
NOMINAL VOWEL /ε/2
LEGEND
/ε/
/ʌ/
NUMBER OF RESPONSES (MAX=20)
20
18
16
14
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11
STEADY STATE DURATION CONDITION

consistent. That is, within any given steady state duration there is no effect of transition length. However, a slight effect can be seen by comparing the panels in Figure 14. Figure 14a summarizes the response pattern for short steady state stimuli (56 ms), while Figure 14b summarizes the response patterns for longer steady state duration stimuli (120 ms). By comparing the panels in Figure 14, it can be seen that the response pattern changes from a two vowel pattern (/ɛ/ vs./ʌ/) (Figure 14a) to a three vowel pattern (/ɛ/ vs. /ʌ/ vs. /ɝ/) (Figure 14b). That is, at the longer steady state durations, the group of listeners maintained an approximately equal number of /ʌ/ responses but the /ɛ/ responses diminished with a concomitant increase in /ɝ/ responses.

Hearing Impaired Subjects

Similar to the responses to the nominal vowels $/I/_1$ and $/I/_2$, hearing impaired listeners were not clearly divergent for the nominal vowels $/\varepsilon/_1$ and $/\varepsilon/_2$. Therefore, the results for both versions of this nominal vowel will be presented on an individual basis with the effects of changes in the formant frequency structure considered within the context of the various duration effects.

Figure 14. Number of responses as a function of transition duration condition. The nominal vowel $/\varepsilon/_2$ served as stimulus. Figure 14a summarizes the results for the 24 ms steady state condition. Figure 14b summarizes the results for a 200 ms steady state condition.



STEADY STATE DURATION 24 ms
NOMINAL VOWEL /ε/2
LEGEND
/ε/
/ʌ/
/ɜ/
A
STEADY STATE DURATION 200 ms
B
NUMBER OF RESPONSES (MAX=20)
0 2 4 6 8 10 12 14 16 18 20
2 3 4 5 6 7 8 9 10 11 5 12 13
TRANSITION DURATION CONDITION

1. <u>Steady State Duration.</u> The response matrices for subject HI-1 are provided as Tables 39 and 40. As with this subject's response matrices for the previous nominal vowels, the patterns of response are somewhat erratic. Again, the large number of empty cells make it difficult to summarize the data. In general, increases in the duration of the steady state yield an increase in the number of empty cells. In other words, if the stimuli are longer in steady state duration, then this subject can not reliably label the tokens. If reliable labels could be assigned, this listener chose /ɔ/.

As with the results for subject HI-1, the response patterns for subject HI-6 were erratic. It can be seen in Tables 41 and 42 that the response patterns are characterized by many empty cells. In contrast to the first subject (HI-1), subject HI-6 chose either /ʊ/ or /ɝ/ for the longer duration /ɛ/$_1$ and /ɛ/$_2$ stimuli. In addition, as can be seen in Table 41, the short duration nominal vowel /ɛ/$_1$ tokens were labeled as /ɚ/, but for the nominal vowel /ɛ/$_2$ tokens the short duration stimuli were labeled /ʌ/ (Table 42). Thus there appears to be differences in the effects of formant frequency structure when the steady state durations are short (i.e., < 140 ms), but these differences do not occur at long steady state durations (Table 41 vs Table 42).

Table 39. Response table for hearing impaired subject HI-1. The nominal vowel /ɛ/$_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I				æ	æ			æ		æ
8	æ		æ		æ	æ			ʊ		ɔ
24	æ								æ		
40	I		æ			æ					
56			æ		a	æ					
72	æ		ɔ		æ						ɔ
88			æ		ɔ	æ			æ		
104	æ					æ			ɝ		
FTD (ms)											
52	æ		æ								ɔ
68	æ					æ					æ
84			æ			æ			ɔ		ɔ
100			æ		ɑ	æ					ɔ
116			æ		æ						ɔ
132			æ								ɔ

Table 40. Response table for hearing impaired subject HI-1. The nominal vowel $/\varepsilon/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)									
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	I		æ		I	æ					
8	æ		ɑ			æ			ɔ		
24	æ		ɔ		æ	æ					ɔ
40	æ		æ		ʊ				ɔ		ɔ
56	æ		a								ɔ
72						ɝ			ɔ		ɔ
88	æ		ɔ		ɔ	ɔ			ɑ		ʊ
104											ɔ
FTD (ms)											
52					ɛ						ɛ
68					æ						ɔ
84	æ				ʊ						
100	æ		a								ɔ
116	æ		ɔ						ɝ		
132	æ		æ		æ						

Table 41. Response table for hearing impaired subject HI-6. The nominal vowel $/\varepsilon_1/$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	æ		ʌ			æ					ɝ
8			ɝ			ɝ			ɝ		ɝ
24			æ								ɝ
40			ʌ			æ					
56	æ				æ	ɔ			ʊ		ɝ
72	ʌ				ɝ	ɝ			ɝ		ɝ
88					æ				ɝ		ʊ
104	ʌ		I		ɝ						
FTD (ms)											
52						ɛ			æ		ɝ
68	ʌ		I			ɝ					ɝ
84	ɪ				ɝ	ɝ					
100	æ				æ	ɔ			ʊ		ɝ
116					ʌ	ɛ					ɝ
132	ɛ								ɝ		ʊ

Table 42. Response table for hearing impaired subject HI-6. The nominal vowel /ɛ/$_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ʌ					ʌ			ʌ		ɝ
8			ɝ		ʌ				ɝ		ɝ
24	ʌ		ɛ		ʌ	ʌ					ʊ
40	ʌ		ɝ		ɝ	ʌ					
56			ɝ		ɝ	ɝ					ɝ
72					ɝ	ɛ			ʊ		ɝ
88	ɛ		ɛ		ɝ	ɝ					
104	ʌ				ɝ	ɚ			ɝ		
FTD (ms)											
52	ʌ		ɚ			ɛ					ɝ
68			ɛ		ɛ				ɝ		ɝ
84	ʌ		ʌ		ʌ				ɝ		
100			ɝ		ɝ	ɝ					ɝ
116	ɛ				a	ɛ			ɝ		
132					ɝ	ʌ					ɝ

In contrast to the first two subjects discussed above, the response patterns for subject HI-2 were somewhat less erratic. In particular, the responses to the nominal vowel $/\varepsilon/_1$ (Table 43) were less erratic than the responses to the nominal vowel $/\varepsilon/_2$ (Table 44). The response patterns for subject HI-2 also had fewer empty cells than either of the first two subjects. This subject chose $/\varepsilon/$ or $/æ/$ for the longest steady state duration stimuli. In addition, changes in either initial or final transition duration had little effect for the nominal vowel $/\varepsilon/_1$ if the steady state was greater than 104 ms.

Subject HI-3 was similar to subjects HI-1 and HI-6 in that there was a large number of empty cells, thus making generalization somewhat difficult. However, there are a few systematic effects that can be seen in Tables 45 and 46. These effects are related primarily to the steady state duration. That is, for long steady state $/\varepsilon/_1$ stimuli, this subject labeled the stimuli as $/ɔ/$. In contrast, increasing steady state duration for the $/\varepsilon/_2$ tokens increased the number of empty cells. This implies that increases in steady state duration decreased the reliability with which this listener could label the tokens.

Table 43. Response table for hearing impaired subject HI-2. The nominal vowel /ɛ/$_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ɛ		ɝ			ɝ			ɛ		æ
8	ɝ		æ		ɝ	æ			æ		æ
24	ɝ		æ		æ	æ			æ		æ
40	ɝ		æ		æ	æ			æ		æ
56	æ		æ		æ	æ			æ		æ
72	æ		æ		æ	æ			æ		æ
88	æ		æ		æ	æ			æ		æ
104	æ		æ		æ	æ			æ		æ
FTD (ms)											
52	æ		æ		æ	æ			æ		æ
68	æ		æ		æ	æ			æ		æ
84	æ		æ		æ	æ			æ		æ
100	æ		æ		æ	æ			æ		æ
116	æ		æ		æ	æ			æ		æ
132	æ		æ		æ	æ			æ		æ

Table 44. Response table for hearing impaired subject HI-2. The nominal vowel /ɛ/$_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ɝ		ɝ		ɝ	ɝ			ɝ		
8	ɝ		ɝ						æ		ɛ
24			æ		ʌ	ɝ			ʌ		æ
40	ɛ		ɝ		ɝ				æ		
56			ɛ		ɛ	æ			æ		ɛ
72			ɛ		æ				æ		ɛ
88	ɛ		ɛ			ɝ			æ		æ
104	ɛ		ɛ ɝ		ɛ	ɛ			ɛ		
FTD (ms)											
52	ɝ		ɝ		ɛ	æ			ɛ		ɛ
68	ɝ		ɝ		ɝ	ɝ			ʌ		
84	ɛ				ɛ	ɛ			ʌ		æ
100			ɛ		ɛ	æ			æ		ɛ
116			ɝ		ɛ	ʌ			æ		æ
132	ɛ		ɛ		æ	ɛ			ɛ		ɛ

Table 45. Response table for hearing impaired subject HI-3. The nominal vowel /ɛ/$_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	æ				æ	æ					æ
8	æ		ɝ			æ			æ		æ
24			æ		ʌ	æ			æ		æ
40	æ		æ		æ						æ
56	æ				æ	æ			æ		ɔ
72			æ		æ	æ			ɝ		
88	æ		æ		æ				ɔ		ɝ
104			ɔ		æ	æ			æ		æ
FTD (ms)											
52	æ		æ		ɝ	æ			æ		ɔ
68	æ		æ		æ	æ			æ		ɔ
84	æ		æ		æ	æ			æ		æ
100	æ				æ	æ			æ		ɔ
116	æ		æ			æ			æ		
132	æ		æ		æ	æ					

Table 46. Response table for hearing impaired subject HI-3. The nominal vowel $/\varepsilon/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0			ʌ						ɝ		ʊ
8	ʌ										ʊ
24									ɔ		
40	ʌ		ʌ			ɥ			æ		
56	ʌ		ɝ						ʊ		
72					ɔ				ɔ		
88			ɔ		ʊ	æ			ɔ		ɔ
104	ɑ		æ			ʊ			ʊ		ɝ
FTD (ms)											
52	ʌ		ʌ			ɔ			æ		ʊ
68			ʊ								
84						ɝ					ɔ
100	ʌ					ɝ			ʊ		
116	ɔ		ɝ		ɔ						
132	ʌ		ʊ								ɔ

Finally, subjects HI-4 and HI-5 were similar to each other in that their response patterns were systematic and there were no empty cells. The response pattern for subject HI-4 (Table 39) indicates that for /ɛ/$_1$ (Table 47) tokens, a change in label from /ɛ/ to /æ/ was elicited. Specifically, at some short steady state durations this subject labeled the stimuli as /ɛ/ and shifted to /æ/ at longer steady state durations. This only occured for the no transition and short initial transition conditions. For the remaining conditions for the nominal vowel /ɛ/$_2$, the response pattern did not change; the response was /æ/. In contrast, as can be seen in Table 48, the /ɛ/$_2$ tokens were labeled /ɛ/ and there were no changes in label as a function of steady state duration.

Finally, subject HI-5 consistently labeled the nominal vowels /ɛ/$_1$ (Table 49) and /ɛ/$_2$ (Table 50) tokens as /æ/. In those few cases where /æ/ was not chosen, the vowel of choice was /ɛ/. There does not appear to be any effects of steady state duration.

In summary, the response patterns of the hearing impaired subjects was again idiosyncratic. That is, for some subjects there was a simple effect of steady state duration, while for others there was a combination of effects of transition duration and steady state duration, and for others there was no effect of steady state or

Table 47. Response table for hearing impaired subject HI-4. The nominal vowel /ɛ/$_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ɛ		ɛ		æ	æ			æ		æ
8	ɛ		ɛ		æ	æ			æ		æ
24	æ		æ		æ	æ			æ		æ
40	æ		æ		æ	æ			æ		æ
56	æ		æ		æ	æ			æ		æ
72	æ		æ		æ	æ			æ		æ
88	æ		æ		æ	æ			æ		æ
104	æ		æ		æ	æ			æ		æ
FTD (ms)											
52	æ		æ		æ	æ			æ		æ
68	æ		æ		æ	æ			æ		æ
84	æ		æ		æ	æ			æ		æ
100	æ		æ		æ	æ			æ		æ
116	æ		æ		æ	æ			æ		æ
132	æ		æ		æ	æ			æ		æ

Table 48. Response table for hearing impaired subject HI-4. The nominal vowel $/\varepsilon/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	ε		ε		ε	ε			ε		ε
8	ε		ε		ε	ε			ε		ε
24	ε		ε		ε	ε			ε		ε
40	ε		ε		ε	ε			ε		ε
56	ε		ε		ε	ε			ε		ε
72	ε		ε		ε	æ			ε		ε
88	ε		ε		ε	ε			ε		ε
104	ε		ε		ε	ε			ε		ε
FTD (ms)											
52	ε		ε		ε						
68	ε		ε		ε	ε			ε		ε
84	ε		ε		ε	ε			ε		ε
100	ε		ε		ε	ε			æ		ε
116	ε		ε		ε	ε			ε		ε
132	ε		ε		ε	ε			ε		ε

Table 49. Response table for hearing impaired subject HI-5. The nominal vowel /ɛ/$_1$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	æ		æ		æ	æ			æ		æ
8	æ		æ		æ	æ			æ		æ
24	æ		æ		æ	æ			æ		æ
40	æ		æ		æ	æ			æ		æ
56	æ		æ		æ	æ			æ		æ
72	æ		æ		æ	æ			æ		æ
88	æ		æ		æ	æ			æ		æ
104	æ		æ		æ	æ			æ		æ
FTD (ms)											
52	æ		æ		æ	æ			æ		æ
68	æ		æ		æ	æ			æ		æ
84	æ		æ		æ	æ			æ		æ
100	æ		æ		æ	æ			æ		æ
116	æ		æ		æ	æ			æ		æ
132	æ		æ		æ	æ			æ		æ

Table 50. Response table for hearing impaired subject HI-5. The nominal vowel $/\varepsilon/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0	æ		æ		æ	æ			æ		æ
8	æ		æ		æ	æ			æ		æ
24	æ		æ		æ	æ			æ		æ
40	æ		æ		æ	æ			æ		æ
56	æ		æ		æ	æ			æ		æ
72	æ		æ		æ	æ			æ		æ
88	æ		æ		æ	æ			æ		ε
104	æ		æ		æ	æ			æ		æ
FTD (ms)											
52	æ		æ		æ	æ			æ		æ
68	æ		æ		æ	æ			æ		æ
84	æ		æ		æ	æ			æ		ε
100	ε		æ		æ	æ			æ		æ
116	æ		ε		æ	ε			æ		
132	æ		æ		æ	ε			æ		æ

transition duration. Also, for some subjects, there was an interaction between the formant frequency structure of the nominal vowels and the effect of steady state duration. Not only were the subjects different from each other, but also, there were only two subjects (HI-4 and HI-5) who had response patterns similar to those of the normal hearing subjects (Tables 51 and 52). This similarity, however, was noted only for the /ɛ/$_1$ tokens. None of the hearing impaired subjects responses patterns were similar to the patterns for the normal hearing subjects for the /ɛ/$_2$ tokens.

As a general summary, then, gross changes in formant frequency as those seen for both versions of the nominal vowels /i, I, ɛ/ yielded different responses in both normal hearing and hearing impaired subjects. Specifically the nominal vowel /i/ elicited primarily /i/ responses from the normal hearing subjects. This was true in the face of changes in the formant frequency structure of the nominal vowel (/i/$_1$ vs. /i/$_2$). However, changes in formant frequency structure for the remaining two nominal vowels evoked responses that changed as a function of the formant structure. For the nominal vowel /I/, normal hearing subjects identified the /I/$_1$ stimuli as either /I/ or /ɛ/. If the F2 formant frequency was lowered as in the /I/$_2$ condition, subjects labeled the stimuli as /ʊ/. For the

Table 51. Response table for the normal hearing subjects. The nominal vowel $/\varepsilon_1/$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0											
8	ε		ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	
24	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
40	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
56	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
72	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
88	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
104	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
FTD (ms)											
52	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
68	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
84	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
100	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
116	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ
132	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ	ɚ

Table 52. Response table for the normal hearing subjects. The nominal vowel $/\varepsilon/_2$ served as stimulus. (Note: ITD=initial transition duration, FTD=final transition duration)

	STEADY STATE DURATION (ms)										
	24	56	72	88	104	120	152	184	200	232	280
ITD (ms)											
0							ʌ	ʌ	ʌ	ʌ	ʌ
8	ʌ	ʌ	ʌ	ʌ			ʌ	ʌ		ʌ	
24	ʌ	ʌ	ʌ	ʌ	ʌ						ʌ
40		ʌ	ʌ	ʌ	ʌ	ʌ		ʌ		ʌ	
56	ʌ	ʌ	ʌ	ʌ		ʌ			ʌ		ʌ
72	ʌ	ʌ	ʌ	ʌ				ʌ	ʌ		
88	ʌ		ʌ	ʌ	ʌ	ʌ	ʌ	ʌ	ʌ	ʌ	
104	ʌ	ʌ		ʌ	ʌ		ʌ			ʌ	
FTD (ms)											
52	ʌ		ʌ	ʌ	ʌ	ʌ				ʌ	ʌ
68	ʌ	ʌ	ʌ			ʌ	ʌ	ʌ			ʌ
84	ʌ	ʌ	ʌ	ʌ	ʌ				ʌ	ʌ	
100	ʌ	ʌ	ʌ	ʌ		ʌ	ʌ		ʌ		ʌ
116	ʌ	ʌ			ʌ	ʌ		ʌ	ʌ		ʌ
132		ʌ	ʌ	ʌ	ʌ	ʌ	ʌ		ʌ		

nominal vowels $/\varepsilon/_1$ and $/\varepsilon/_2$, normal hearing subjects consistently identified the stimuli as /æ/ or /ʌ/, respectively.

Finally, some individual variability was noted in the response behavior of the normal hearing subjects. However, the responses of the hearing impaired subjects was highly variable and idiosyncratic. Not only were the hearing impaired subjects different from the normal hearing subjects, but they also were different from each other. Also, the effects of steady state duration and initial and final transition durations were different for each vowel for each subject.

CHAPTER IV

DISCUSSION

The results of this vowel identification study add further support to the notion of the complexity of the perceptual process. In general, this perceptual process is a complex multi-cued phenomenon in which the significance of the various cues depends in part on the other cues in the stimulus. That is, for a given nominal vowel, the effects of steady state duration depend in part on the formant frequency location and the duration of the initial or final transition or both. Thus, the salience of the cues appears to be somewhat fluid and the contribution of any cue depends in part on the cue set available to the listener. In addition, while the effects of a given cue within a particular nominal vowel and vowel context condition are similar across the normal hearing subjects, the effects are different for the hearing impaired subjects. Further, not only are the effects different for the normal hearing and hearing impaired groups but the effects also are different within the hearing impaired group.

Prior to considering the results in greater detail, two points need to be made. One, while the normal hearing data are interesting in their own right, these data are used to validate the stimuli and serve as guidelines for expectations with regard to the hearing impaired listeners. Two, it is acknowledged that there are a number of possible interpretations of the data; however, the goal is to describe the effects of hearing loss on a listener's ability to use the multiple cues to label the vowel-like stimuli. Thus, initially, the results from the normal hearing listeners will be discussed as a backdrop for a discussion of the effects of hearing loss on the use of a fluid cue set. In addition, because the stimuli were generated to be different in terms of spectral and durational characteristics, this chapter will proceed with a discussion of the effects of spectral changes followed by the effects of durational characteristics.

Spectral Effects

Traditionally, the salience of vowel formant frequency structure led to the generation of various "target" hypotheses to account for the outcomes in vowel perception research. Thus, the general thrust of the early research was to identify the spectral characteristics or formant frequency structure that uniquely defines the vowel (Delattre et al., 1952; Joos, 1948, Peterson and Barney, 1952). The extent to which formant frequency structure affects vowel identification can be seen in Figures 15, 17, and 19. These figures summarize the response patterns for the normal hearing listeners for the nominal vowel $/i/_1$, $/I/_1$, and $/\varepsilon/_1$, respectively. These nominal vowels differ in terms of frequency characteristics and, as can be seen in the response patterns, differ perceptually for this group of listeners. In addition, Figures 16, 18, and 20 summarize the identification data for the normal hearing subjects for the nominal vowels $/i/_2$, $/I/_2$, and $/\varepsilon/_2$, respectively. Comparisons of the response patterns for the nominal vowels $/i/_1$, $/I/_1$ and $/\varepsilon/_1$ and $/i/_2$, $/I/_2$ and $/\varepsilon/_2$ allow obervations of the effects of gross spectral changes on the response patterns. In addition, comparisons between the response patterns within a given nominal vowel (i.e., Figure 15 vs. Figure 16 or Figure 17 vs. Figure 18 or Figure 19 vs. Figure 20) allow observations of the effects of smaller spectral changes in F1, F2, and F3. For example, in comparing the labeling of the two versions of the nominal vowel /ɛ/ in Figures 19 and 20, it is clear that small changes in formant frequency structure also

Figure 15. Response pattern of the normal hearing subjects. See document for details of the calculation of the indices. The nominal vowel was /i/$_1$. Figure 15a represents the response pattern for a stimulus with a variable initial transition. Figure 15b represents the response pattern for a stimulus with a variable final transition.

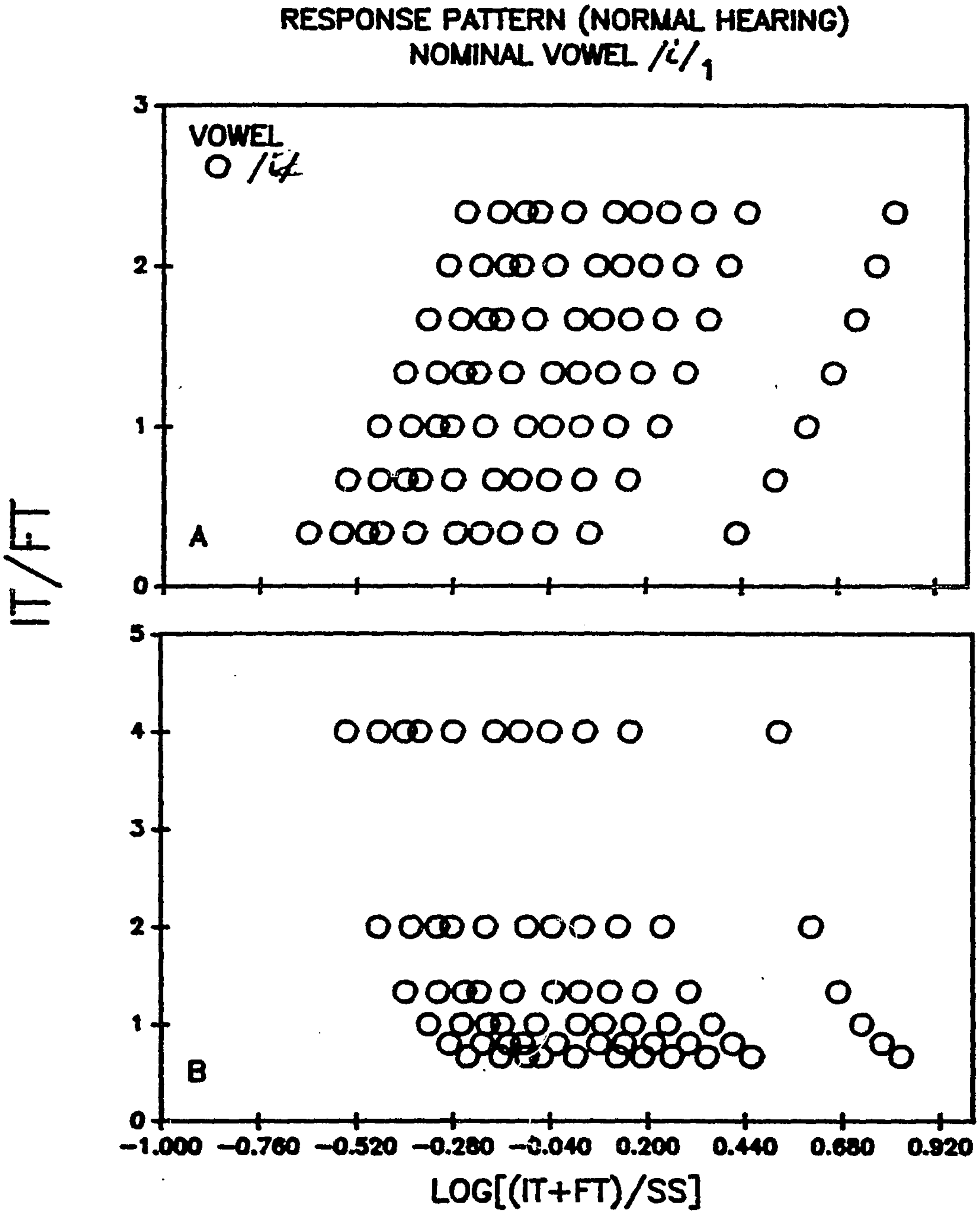
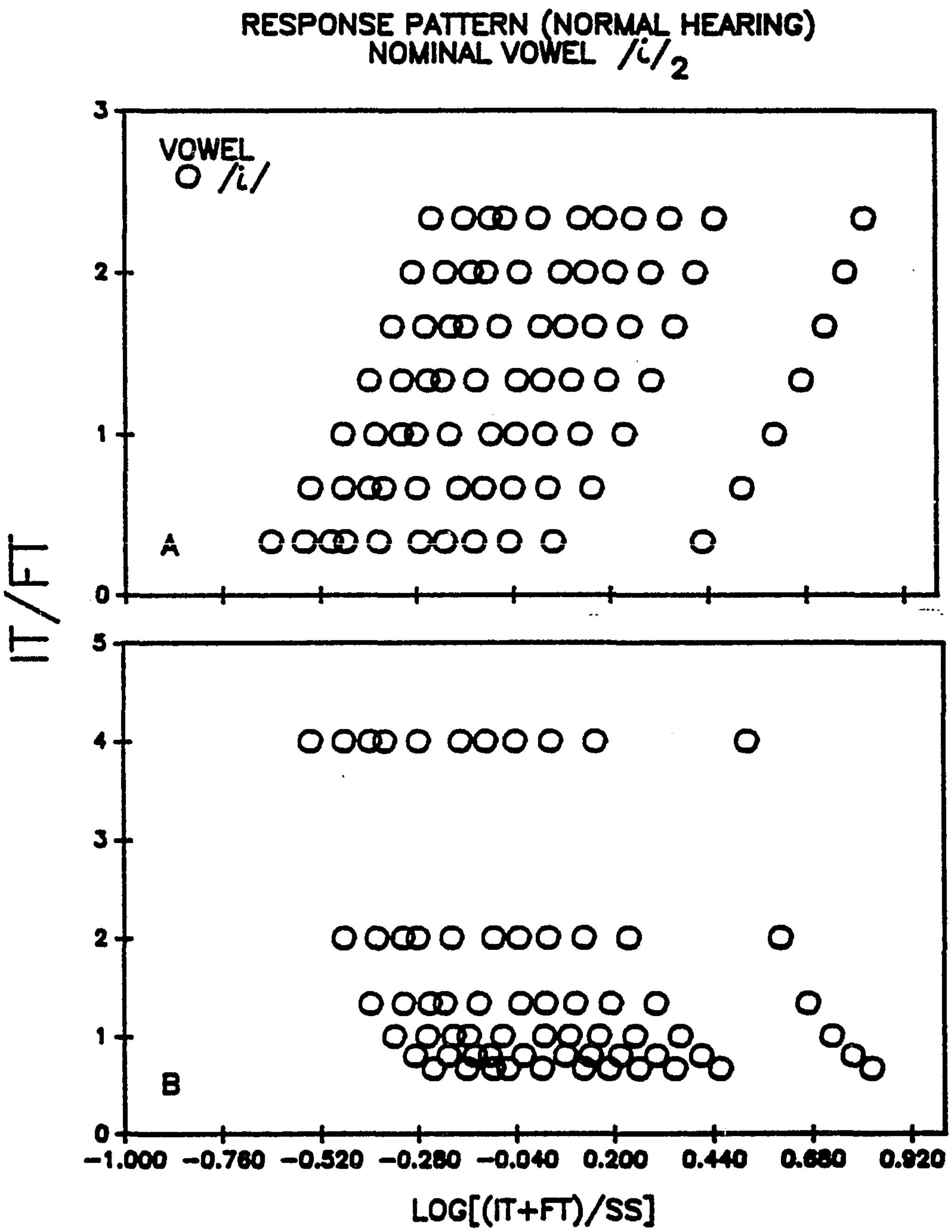

RESPONSE PATTERN (NORMAL HEARING)
NOMINAL VOWEL /i/₁
VOWEL
O /i/
A
B
IT/FT
LOG[(IT+FT)/SS]
-1.000 -0.760 -0.520 -0.280 -0.040 0.200 0.440 0.680 0.920

Figure 16. Response pattern of the normal hearing subjects. See document for details of the calculation of the indices. The nominal vowel was /i/$_2$. Figure 16a represents the response pattern for a stimulus with a variable initial transition. Figure 16b represents the response pattern for a stimulus with a variable final transition.



RESPONSE PATTERN (NORMAL HEARING)
NOMINAL VOWEL /i/2
VOWEL
O /i/
A
B
IT/FT
0
1
2
3
4
5
-1.000 -0.760 -0.520 -0.280 -0.040 0.200 0.440 0.680 0.920
LOG[(IT+FT)/SS]

Figure 17. Response pattern of the normal hearing subjects. See document for details of the calculation of the indices. The nominal vowel was $/I/_1$. Figure 17a represents the response pattern for a stimulus with a variable initial transition. Figure 17b represents the response pattern for a stimulus with a variable final transition.

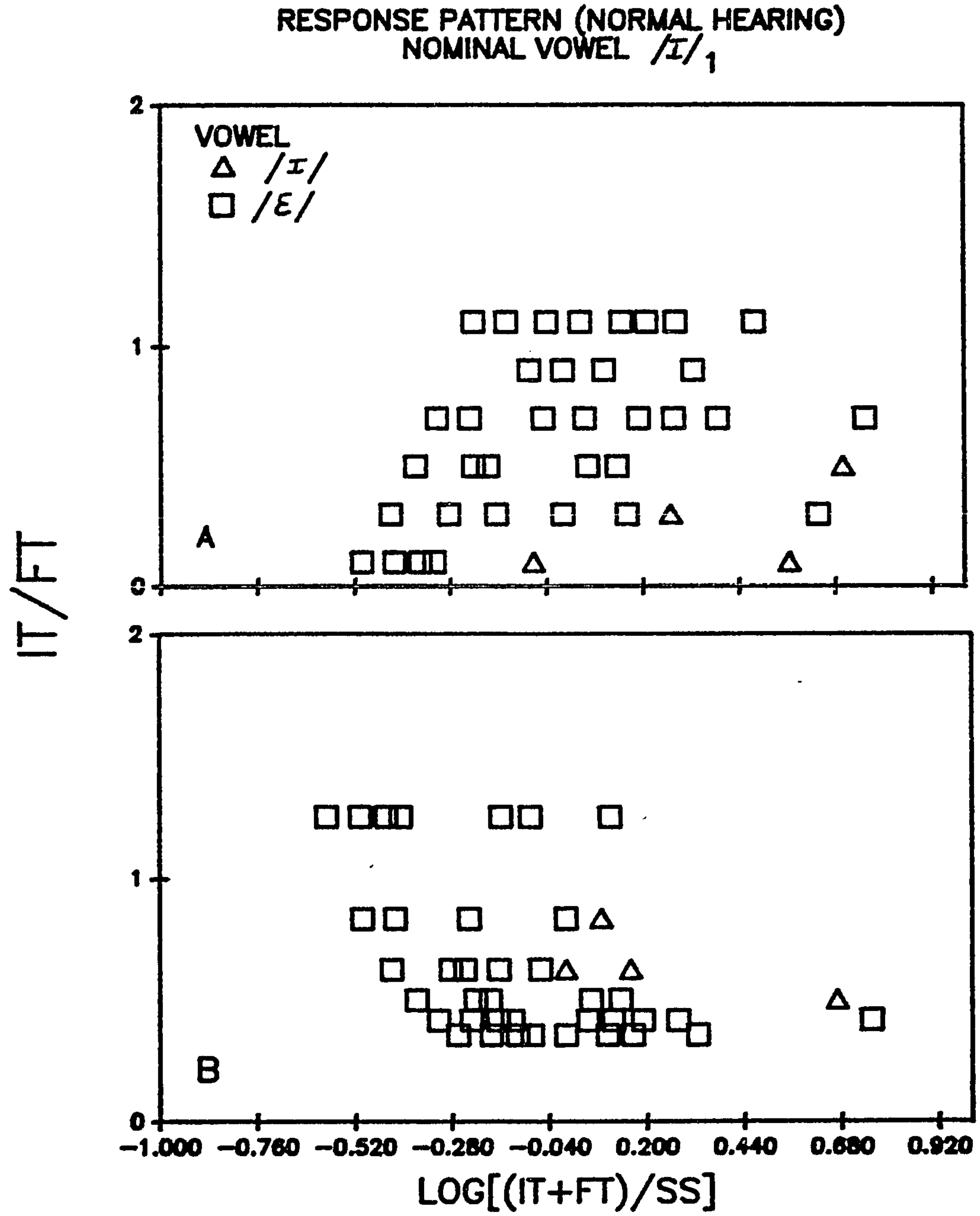

RESPONSE PATTERN (NORMAL HEARING)
NOMINAL VOWEL /ɪ/ 1
VOWEL
△ /ɪ/
□ /ɛ/
A
B
2
1
0
IT/FT
−1.000 −0.760 −0.520 −0.280 −0.040 0.200 0.440 0.680 0.920
LOG[(IT+FT)/SS]

Figure 18. Response pattern of the normal hearing subjects. See document for details of the calculation of the indices. The nominal vowel was $/I/_2$. Figure 18a represents the response pattern for a stimulus with a variable initial transition. Figure 18b represents the response pattern for a stimulus with a variable final transition.

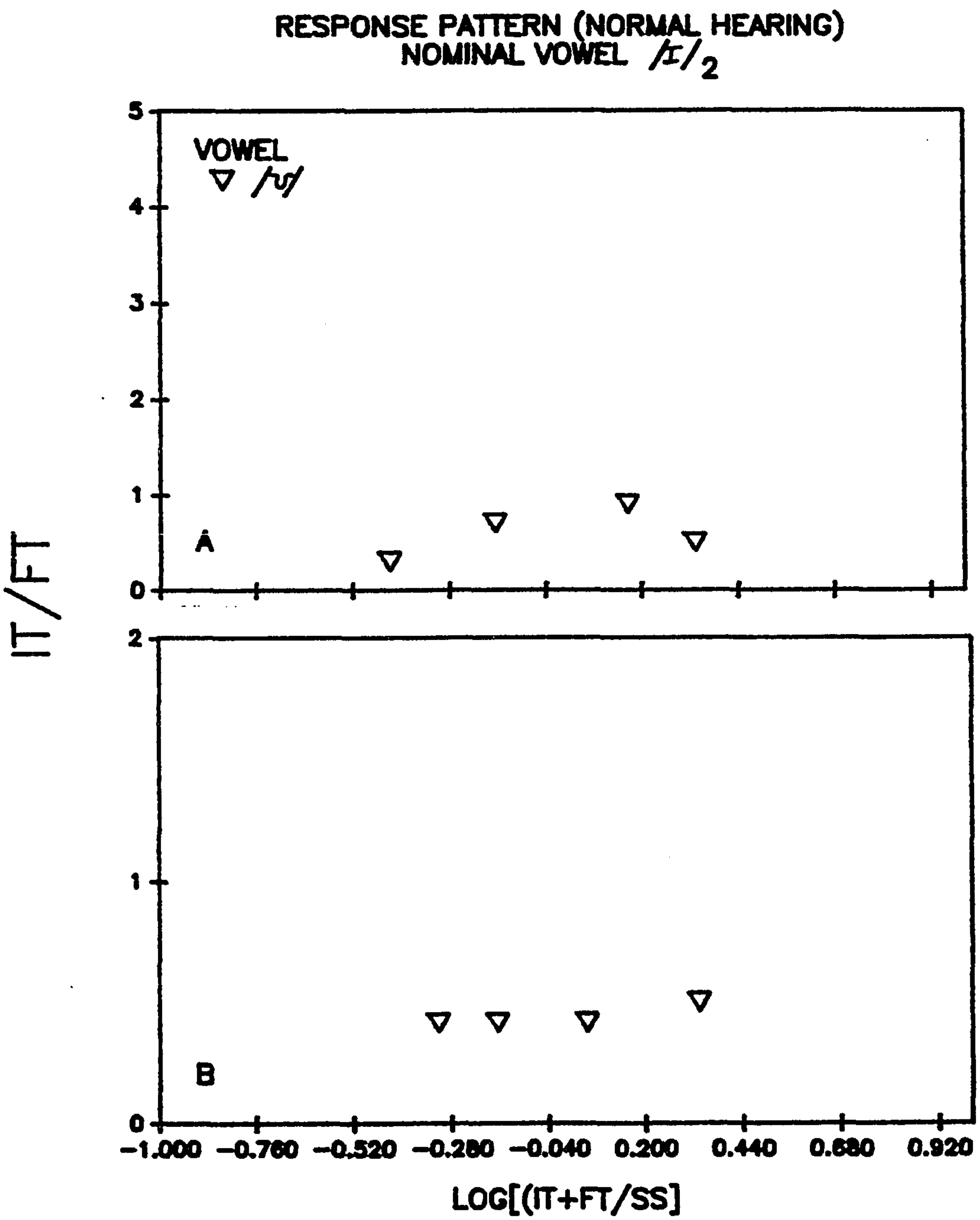

RESPONSE PATTERN (NORMAL HEARING)
NOMINAL VOWEL /ɪ/$_2$
VOWEL
▽ /ʊ/
A
B
IT/FT
LOG[(IT+FT/SS]
-1.000 -0.760 -0.520 -0.280 -0.040 0.200 0.440 0.680 0.920
0 1 2 3 4 5
0 1 2

Figure 19. Response pattern of the normal hearing subjects. See document for details of the calculation of the indices. The nominal vowel was $/\varepsilon/_1$. Figure 19a represents the response pattern for a stimulus with a variable initial transition. Figure 19b represents the response pattern for a stimulus with a variable final transition.

RESPONSE PATTERN (NORMAL HEARING)
NOMINAL VOWEL /ɛ/$_1$

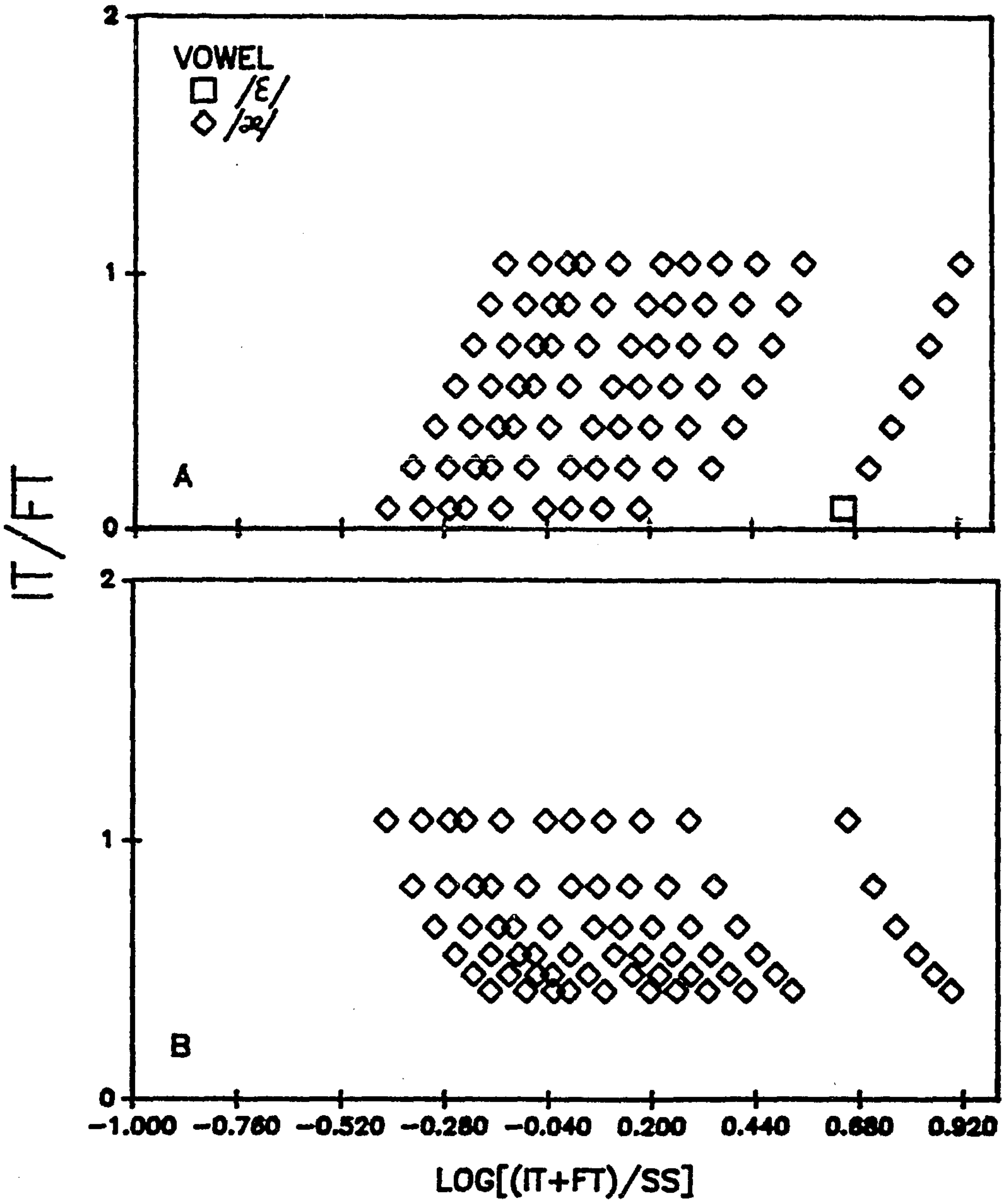
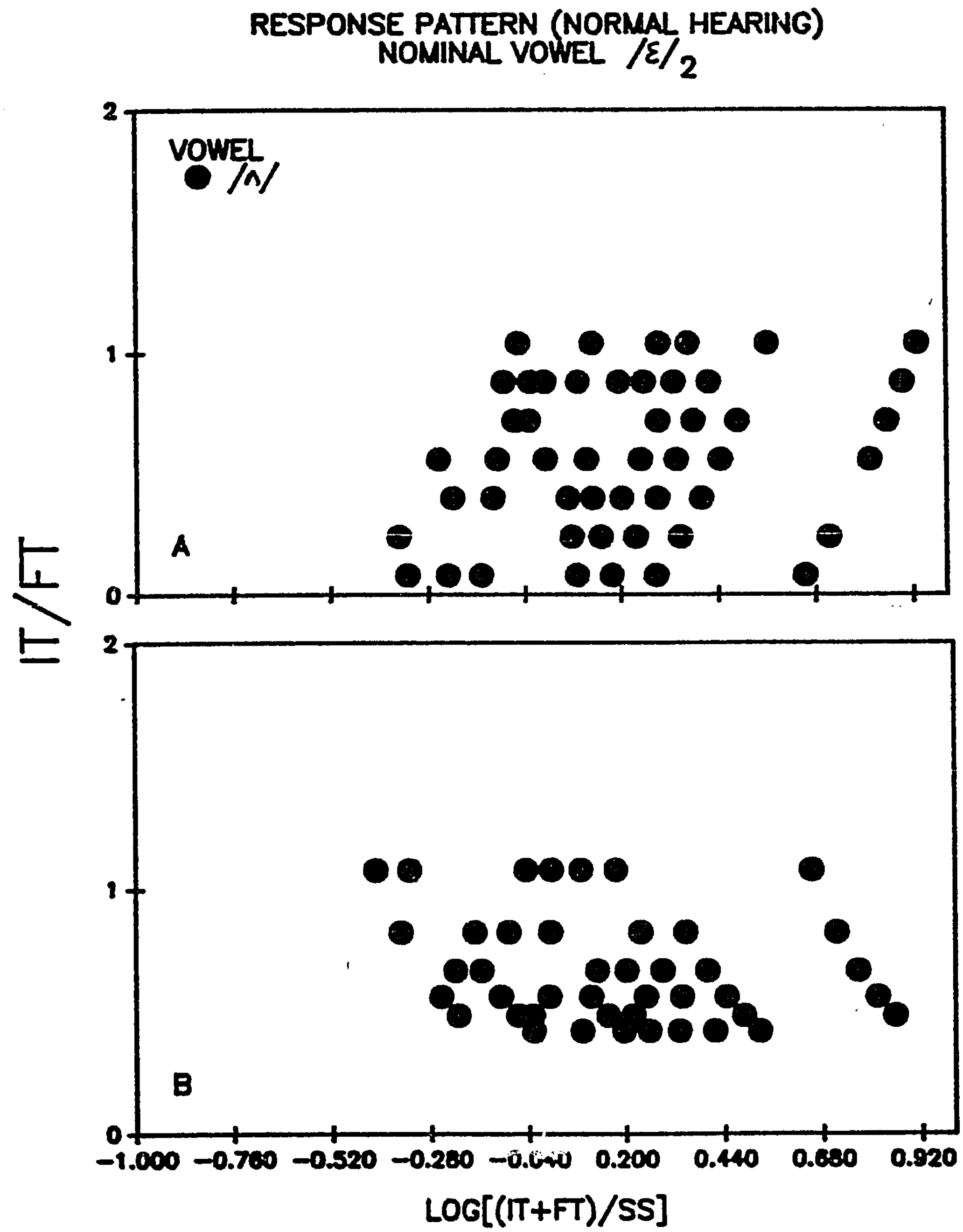


Figure 20. Response pattern of the normal hearing subjects. See document for details of the calculation of the indices. The nominal vowel was $/\varepsilon/_2$. Figure 20a represents the response pattern for a stimulus with a variable initial transition. Figure 20b represents the response pattern for a stimulus with a variable final transition.


RESPONSE PATTERN (NORMAL HEARING)
NOMINAL VOWEL /ɛ/$_2$
VOWEL
/ʌ/
A
B
IT/FT
2
1
0
2
1
0
−1.000 −0.760 −0.520 −0.280 −0.040 0.200 0.440 0.680 0.920
LOG[(IT+FT)/SS]

signal changes in vowel identity. That is, by lowering the F2 value for the nominal vowel /ɛ/ the effect is one of signalling a change in vowel identity from /ɛ/ to /æ/. A change in labels with changes in formant structure is also apparent for the nominal vowels /I/$_1$ and /I/$_2$ (Figure 17 vs. Figure 18). The effect, however, is not present for the nominal vowels /i/$_1$ and /i/$_2$ (Figure 15 vs. Figure 16). Thus, as expected, the changes in spectral characteristics yielded changes in labels as would be predicted by the work of previous researchers (Joos, 1948; Peterson and Barney, 1952; Potter and Peterson, 1948; and Potter and Steinberg, 1950; Syrdal and Gopal, 1986). However, while this effect is apparent in Figures 15-20, there are cases in which the same formant frequency structure generates a different identification (e.g., short steady state duration tokens of /I/$_1$ and long steady state duration tokens of /I/$_1$. These are indicated with an asterisk in Figure 17).

Durational Effects

Several lines of converging evidence are important to consider when evaluating the data from this experiment. As will be recalled from the literature review, durational cues are generally considered to contribute information regarding tense/lax contrasts for vowel tokens. This contrast may be cued either by the intrinsic durational properties of the vowel or by the effects of duration of the various portions of the vowel (i.e., initial transition portion, steady state portion, or final transition portion). In particular, with regard to the transition portions of the vowel, the tense/lax contrast may be cued by the absolute transition durations or some ratio of the transitions or both.

Again, then, the tense/lax distinction is a complex multi-cued process. Thus, the distinction can be cued by more than one durational effect and does not have to be a simple absolute durational effect; although that too may be possible.

Prior to proceeding with this point, it is appropriate to bear in mind a caution regarding the relationships between physical duration and perceived duration. As should be recalled, there is not necessarily an isomorphism with regard to duration in the acoustic stimulus and the effective stimulation time. This has been demonstrated in terms the perceived vowel duration (Rapheal, Dorman and Liberman, 1980) and in terms of the effects of rising vs. falling transitions (Collins, 1984; Collins and Cullen, 1978). To facilitate the discussion of the results, a simplifying assumption was made. In particular, it was assumed that while the perceptual transformation of physical duration was not necesarily linear, there was a monotonic increase in perceptual duration with an increase in physical duration.

In contrast to the comparatively simple relationship between formant frequency structure and vowel identity, the tense/lax contrast as signalled by durational cues is complex. To examine the effects of durational cues, the data will be evaluated in terms of 1) steady state duration, and 2) absolute transition duration.

Steady State Duration Effects

Table 53 summarizes the the changes in labeling that occured with increasing steady state duration. The data that are included in this table are the two responses that were most commonly selected for each nominal vowel. Specifically, as seen in Table 53, changes in steady state duration of the nominal vowel $/i/_1$ and $/i/_2$ did little to affect the identification performance of this group of listeners. These results were in agreement with the work of Ainsworth (1971) in which changes in steady state duration did not appear to be important in the identification of the non-mid vowels. If a change in the identification process were to have occurred, the options for this vowel would be limited for two reasons. One, the intrinsic duration of /i/ is long so that if duration was a

Table 53. Number of responses as a function of steady state duration for the nominal vowels /i/1, /i/2, /I/1, /I/2, /ɛ/1, and /ɛ/2. The stimuli were steady state only tokens ofthe nominal vowels.

		Steady State Duration (ms)										
		24	56	72	88	104	120	152	164	200	232	280
$/i/_1$												
	/i/	17	20	19	19	20	20	19	18	19	20	20
	/I/	3	0	1	1	0	0	1	2	1	0	0
$/i/_2$												
	/i/	19	18	19	17	20	20	19	19	20	20	19
	/I/	1	2	1	3	0	0	1	0	0	0	1
$/I/_1$												
	/I/	12	6	12	14	13	9	10	9	11	5	5
	/ɛ/	8	13	8	6	7	10	10	11	9	15	14
$/I/_2$												
	/I/	8	6	6	3	3	7	2	2	4	3	2
	/ʊ/	3	7	8	8	9	9	10	10	9	11	7
$/ɛ/_1$												
	/ɛ/	8	10	12	11	5	8	6	4	5	6	7
	/æ/	12	10	8	9	15	12	14	16	15	14	12
$/ɛ/_2$												
	/ɛ/	10	6	12	6	7	10	3	6	6	4	4
	/ʌ/	7	10	6	12	8	8	15	13	14	16	14

primary cue, then listeners would be more likely to confuse /i/ with other tense vowels (Strange, Edman, and Jenkins, 1979). Yet the logical alternatives /a,ɔ,u/ are different from each other with regard to formant frequency structure and thus unlikely to be confused by normal hearing listeners. In contrast, it would be expected that the responses for the nominally lax vowels $/I/_1$, $/I/_2$, $/\varepsilon/_1$ and $/\varepsilon/_2$ would be confusable with spectrally similar vowels. That is, durational and spectral information may be needed to uniquely specify the tokens. As can be seen in Table 1, this expectation holds. For example, the most commonly used alternative responses for $/I/_1$ and $/I/_2$ were /I/ or /ɛ/, both lax vowels. It is interesting to note that as the steady state duration increases the perceived vowel shifts to one that is lower in the F2 domain for both versions of the nominal vowels /I/ and /ɛ/. These findings are in general agreement with Ainsworth's 1981 study in which it was hypothesized that there is a region of equivalence of duration and formant frequency. For example, consider the results for the longer $/I/_1$ and the shorter $/\varepsilon/_1$. Both were labeled the same, but differed in terms of frequency as well as durational characteristics. It is clear, then, from these results that a number of cues can be used to effect the same labeling behavior, and there appears to be a difference in the salience of a given cue as a function of the other elements of the cue set.

Careful examination of Figures 15-20 permits insight into the effects of steady state duration on the identification behavior of normal hearing listeners. Before examining these figures, several points concerning the figures need to be considered. First, each figure has two parts (a & b). Consider for example, Figure 15a and Figure 15b. These two figures differ from each other in terms of the conditions that are plotted. In particular, the responses plotted in Figure 15a are for those stimuli in which the duration of the intial transition was varied while the final transition duration was fixed. The responses summarized in Figure 15b are for those stimuli in which the initial transition duration was fixed and the final transition duration was varied.

Second, in order to plot the responses, two indices were calculated for each stimulus condition. An index, (r_1), was calculated to categorize the data in terms of the relative durational characteristics of the transitional portions of the token to the durational characteristics of the steady state portions of the token. This index was derived using equation 1.

$$r_1 = \log[(IT+FT)/SS] \qquad (1)$$

where IT=initial transtion duration

FT=final transition duration

SS=steady state duration

A second index, (r_2), was calculated to categorize the data with respect to the ratio of the initial transition duration to the final transition duration. Equation 2 was used to generate this index.

$$r_2 = IT/FT \qquad (2)$$

Thus all points that fall on a given line rising from left to right represent stimuli that had the same steady state duration. Each curved line represents a different steady state duration condition with the leftmost line indicating the longest steady state duration (280 ms) and the line furthest to the right indicating the shortest steady state duration (24 ms). Further, all points that fall on a given line parallel to the x-axis had the same transition duration. Also, in Figures 15a-20a, as r_2

increases, the duration of the initial transition increases. Therefore, the total duration of the stimulus increases as r_1 decreases. In addition, the total duration increases as r_2 increases within any given steady state duration. For Figures 15b-20b, as r_2 increases, the final transition duration decreases, and thus within any given steady state duration condition the total duration decreases. As with Figures 15a-20a, moving from right to left within any given transition duration in Figures 15b-20b indicates an increase in total stimulus duration.

Also, in comparing within the same figure (for example, Figures 15a vs. 15b) there are cases in which the values of r_1 are equal for some of the points in each figure. If r_1 is equal, this implies that the steady state portions and the transition portions were in the same ratio. They differed, however, in the relative duration of the initial transition to the final transition.

With this orientation in mind, careful examination of Figures 17a and 18a indicates that one of two things occur with increases in initial transition duration. One, there are regions in which consistent responses (i.e., greater than or equal to 65 % consistency) are not obtained and two, if there is a shift in the responses, it is toward a vowel that is typically lower in F1/F2 space. This finding is consistent with the Ainsworth (1981) data. That is, with a fixed formant frequency structure, increasing duration has an effect of generating the perception of a vowel that is lower in an acoustic/articulatory space. Therefore, there appears to be a change in the relative salience of formant frequency vs. transition duration formation when the latter is sufficiently long. Perhaps the most interesting implications of these results are found in the regions in which consistent responses were not obtained. In particular, it may be hypothesized that the presence of conflicting cues may have precluded a stable response pattern. Thus, it is in this region that future work may prove fruitful in attempts to understand the complex cue interactions.

Evaluation of Figures 19a and 20a also indicates that there were regions in which consistent responses to the nominal vowels $/\varepsilon/_1$ and $/\varepsilon/_2$ were not obtained. Further, the vowels that were consistently identified did not appear to change with changes in initial transition duration.

The changing salience related to initial transition duration that was present for the nominal vowels $/I/_1$ and $/I/_2$ was not apparent for either version of the nominal /i/ or /ɛ/ vowels. Thus, as seen in Figures 15a, 16a, 19a, and 20a, the initial transition information is not sufficient to generate changes in the labels assigned to the stimuli. It appears, then that within these frequency regions (i.e., F1/F2/F3 for $/i/_1$ & $/i/_2$ and $/\varepsilon/_1$ & $/\varepsilon/_2$) durational information does not effect a change in labeling responses. Yet as seen in Figures 17a and 18a, the transition duration information does appear to affect the labeling responses. Again, because the effect of initial transition duration varies with formant frequency strucuture of the stimuli, the process is clearly a multi-cued complex process.

Evaluation of Figures 15b-20b, reveals that only responses to the nominal $/I/_1$ and $/I/_2$ are susceptible to final transtion duration changes. These changes are in an opposite direction to that which would be predicted on the basis of production data. Specifically, short final transition durations may be expected to cue a tense vowel. However, because the area in which the response labels are different are only at the short duration steady state conditions, it might be hypothesized that the steady state duration effects dominate the final transition effects. Again this points to the complex and perhaps changing salience of the cue set.

To account for the sparseness of effects with normal hearing listeners, several hypotheses should be considered. First, the formant frequency structure may have specified a perceptual region over which the durational changes used in this study were ineffective. Specifically, if a tense vowel is adequately specified by formant frequency strucutre it may not be possible to generate initial transitions that are sufficiently long to shift the perception to a lax vowel. Rather, such a change in initial transition duration may deny the possibility of a lax vowel and generate the perception of a glide or diphthong. Second; it is hypothesized that an effect of duration may have occurred, however, because the experiment was conducted using a 10 alternative forced choice response paradigm, the effects were not measurable. A final hypothesis to be considered is one in which the effects that were of interest (i.e., complex interplay of cues) did in fact occur, but isolation of the effect did not result because the changing salience or fluidity masked any effect.

In summary, while the complexity and interactions within the cue set are readily apparent for only one nominal vowel ($/I/_1$, $/I/_2$), it is not apparent for $/i/_1$, $/i/_2$ and $/\varepsilon/_1$ $/\varepsilon/_2$. As mentioned earlier this lack of apparent effect does not necessarily imply the absence of an effect. But rather, the effect may be masked or the salience of any one cue may be sufficient to allow identification of a vowel without interference from other cues.

If one of the elements in the cue set is limited, then perhaps the interactions within the cue set may become more apparent as the degrees of freedom for the interactions are reduced. Thus, reducing the degrees of freedom may have an effect of reducing the ability to use the changing salience of the full cue set or may have an effect of changing a weighting pattern within the cue set to compensate for the decrease in the degrees of freedom.

Hearing impaired subjects are faced with the problem of using a cue set that has been reduced in terms of the degrees of freedom. That is, the impact of hearing loss is such that these listeners are faced with a reduced ability to extract information from a acoustic stream. In particular, the cue set may be impoverished and/or distorted.

A simplistic view of hearing impairment would suggest that the deficit causes some of the cues to be inaudible. This inaudibility, then, should leave the listener with a reduced cue set; but because the speech signal is redundant, little effect of the deficit is expected unless, of course, the magnitude of the loss is great. If an effect is present, however, the outcome would be predictable on the basis of the "missing" cues. However, the effects of hearing loss may be such that there is distortion in the extraction of spectral information. Perhaps these effects would generate a distorted cue set rather than an impoverished cue set.

This simplistic view should be expanded to include the possibility of a reduction in the contribution of durational information to the perceptual process. That is, hearing impaired listeners may have difficulty extracting temporal information from the acoustic stream and thus the cue set would be limited. However, the effects of the limitations imposed on the cue set by temporal extraction difficulties would be different from the limitations imposed by a spectral extraction problem. Finally, it is possible that the cue set may be reduced in both spectral and durational characterisitcs. Thus the relative effect of each reduction may be dependent on the listener and his/her ability to weight the cue set to achieve maximum identification performance. It should be noted that it is unlikely that the remaining cue set would be free of distortion introduced by the hearing loss.

In general, then, hearing impaired listeners must solve the unique problem(s) imposed by their hearing loss. The changes in the cue set may be a simple translation from a full spectral/temporal complement of cues to a reduced spectral complement and a full durational complement of cues. In that case, if the hearing loss is high frequency in nature then the tense vowels /i,u/ may be confused with their near neighbors in the acoustic/articulatory space. However, if the durational cue set is intact, a long initial transition may be sufficient to distinguish /i/ from /I/. As can be seen in Figures 21a-24a this expectation holds for 4 of the 6 hearing impaired subjects (HI-4, HI-2, HI-5, HI-6 respectively) but does not hold for the remaining two subjects (Figures 25a and 26a). That is, the /i/ label which was consistently assigned to the stimuli by the normal hearing subjects was also reliably assigned by these hearing impaired subjects in spite of significant high frequency hearing loss. In contrast, subject HI-3) (Figure 25a) appears to use either the transition information or total duration information and thus identifies the nominal $/i/_1$ tokens as /I/ if the stimuli have short steady state durations ($<$ 120 ms) or short initial transitions ($<$ 16 ms). Thus the response patterns for this subject were not determined exclusively by either spectral or durational cues.

Subject HI-1 (Figure 26a), who has a flat hearing loss, consistently performed differently from the other hearing impaired subjects. As can be seen in Figure 26a, this subject's behavior was somewhat erratic. She may have been faced with a cue set that was distorted both in terms of spectral and durational characteristics. While it is

Figure 21. Response pattern of hearing impaired subject HI-4. See document for details of the calculation of the indices. The nominal vowel was $/i/_1$. Figure 21a represents the response pattern for a stimulus with a variable initial transition. Figure 21b represents the response pattern for a stimulus with a variable final transition.

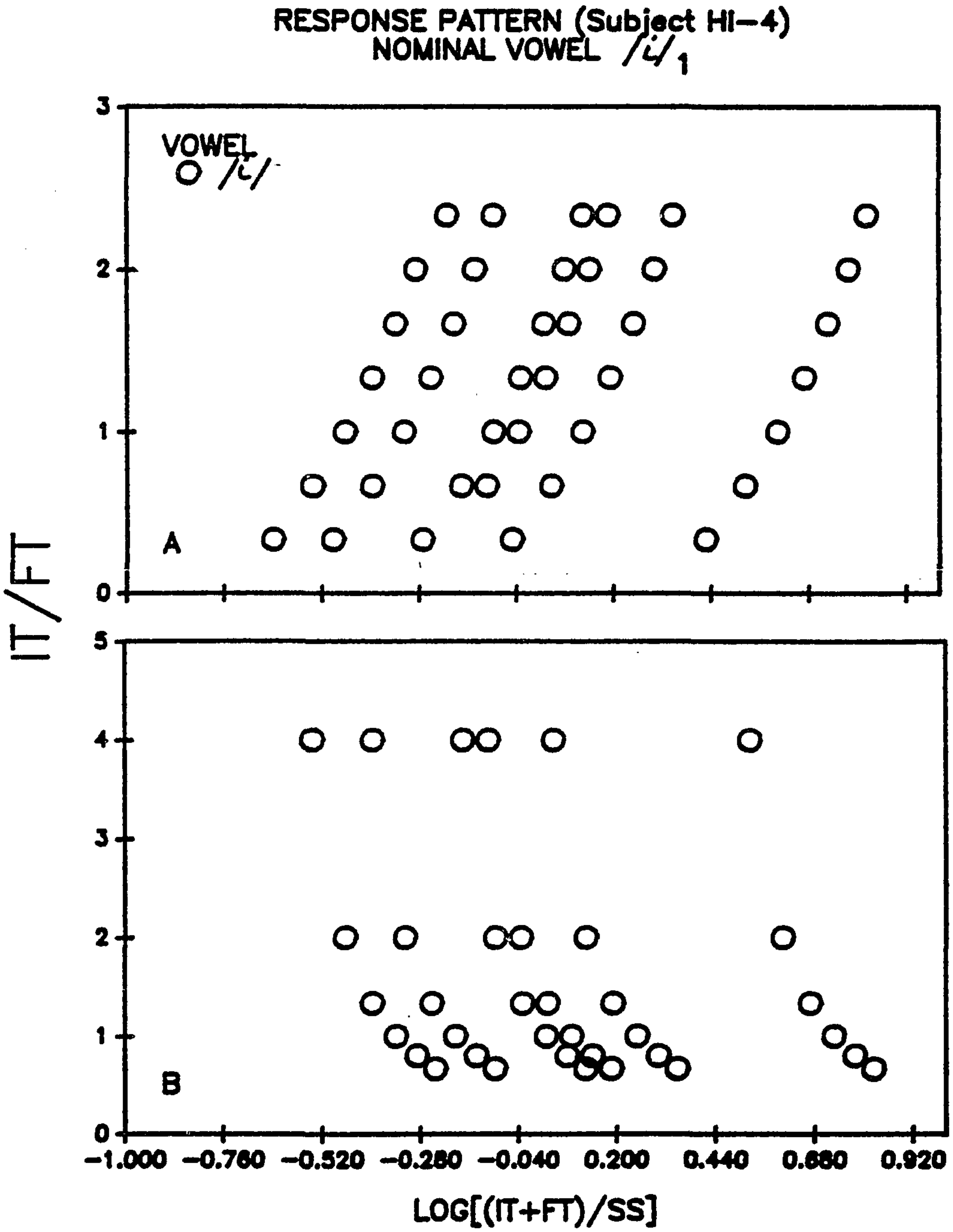

RESPONSE PATTERN (Subject HI-4)
NOMINAL VOWEL /i/1
VOWEL
O /i/
A
B
IT/FT
0
1
2
3
4
5
-1.000 -0.760 -0.520 -0.280 -0.040 0.200 0.440 0.680 0.920
LOG[(IT+FT)/SS]

Figure 22. Response pattern of hearing impaired subject HI-2. See document for details of the calculation of the indices. The nominal vowel was $/i_1/$. Figure 22a represents the response pattern for a stimulus with a variable initial transition. Figure 22b represents the response pattern for a stimulus with a variable final transition.

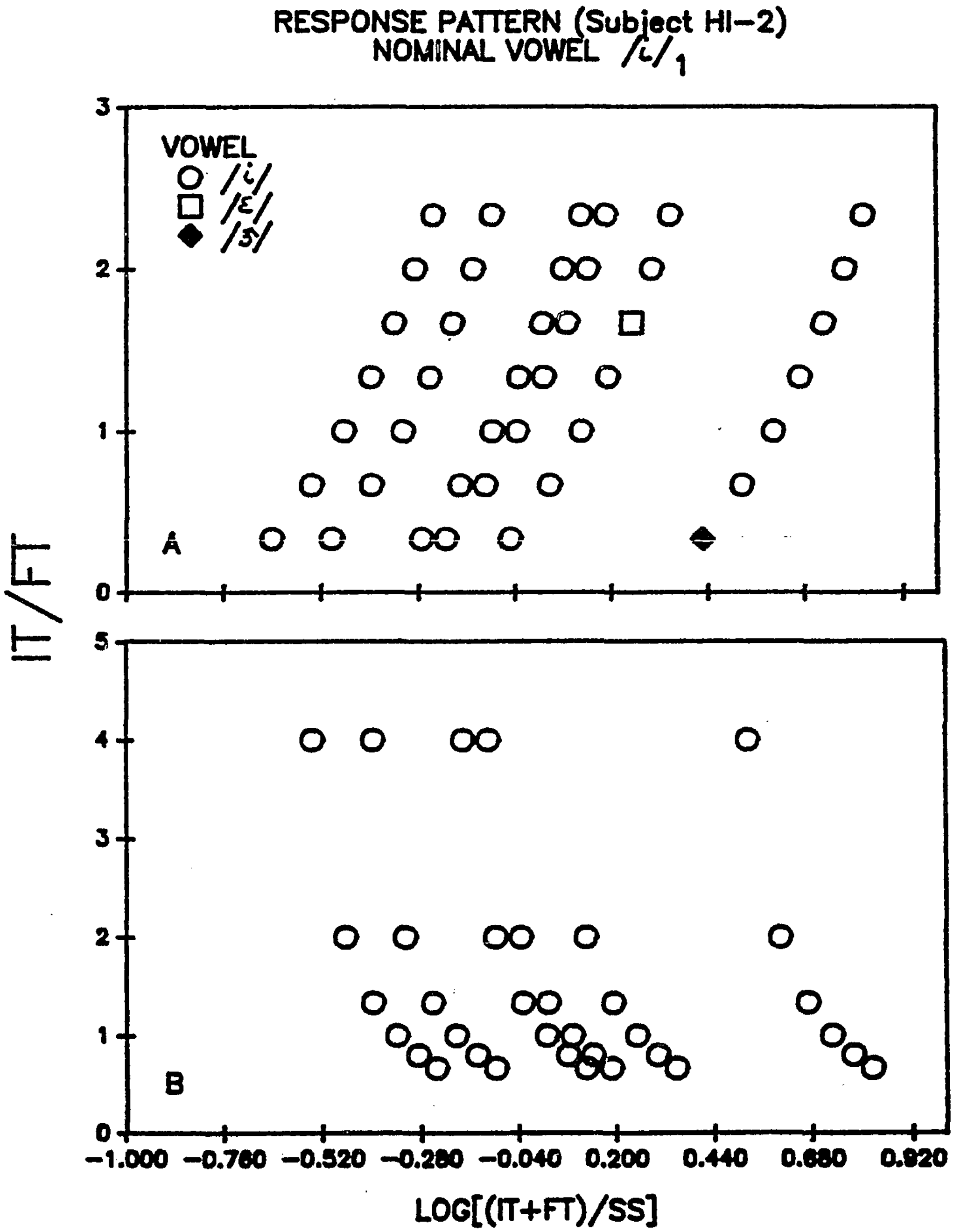

RESPONSE PATTERN (Subject HI-2)
NOMINAL VOWEL /ɪ/$_1$
VOWEL
/i/
/ɛ/
/ɔ/
A
B
IT/FT
0
1
2
3
4
5
-1.000
-0.760
-0.520
-0.280
-0.040
0.200
0.440
0.680
0.920
LOG[(IT+FT)/SS]

Figure 23. Response pattern of hearing impaired subject HI-5. See document for details of the calculation of the indices. The nominal vowel was /i/$_1$. Figure 23a represents the response pattern for a stimulus with a variable initial transition. Figure 23b represents the response pattern for a stimulus with a variable final transition.

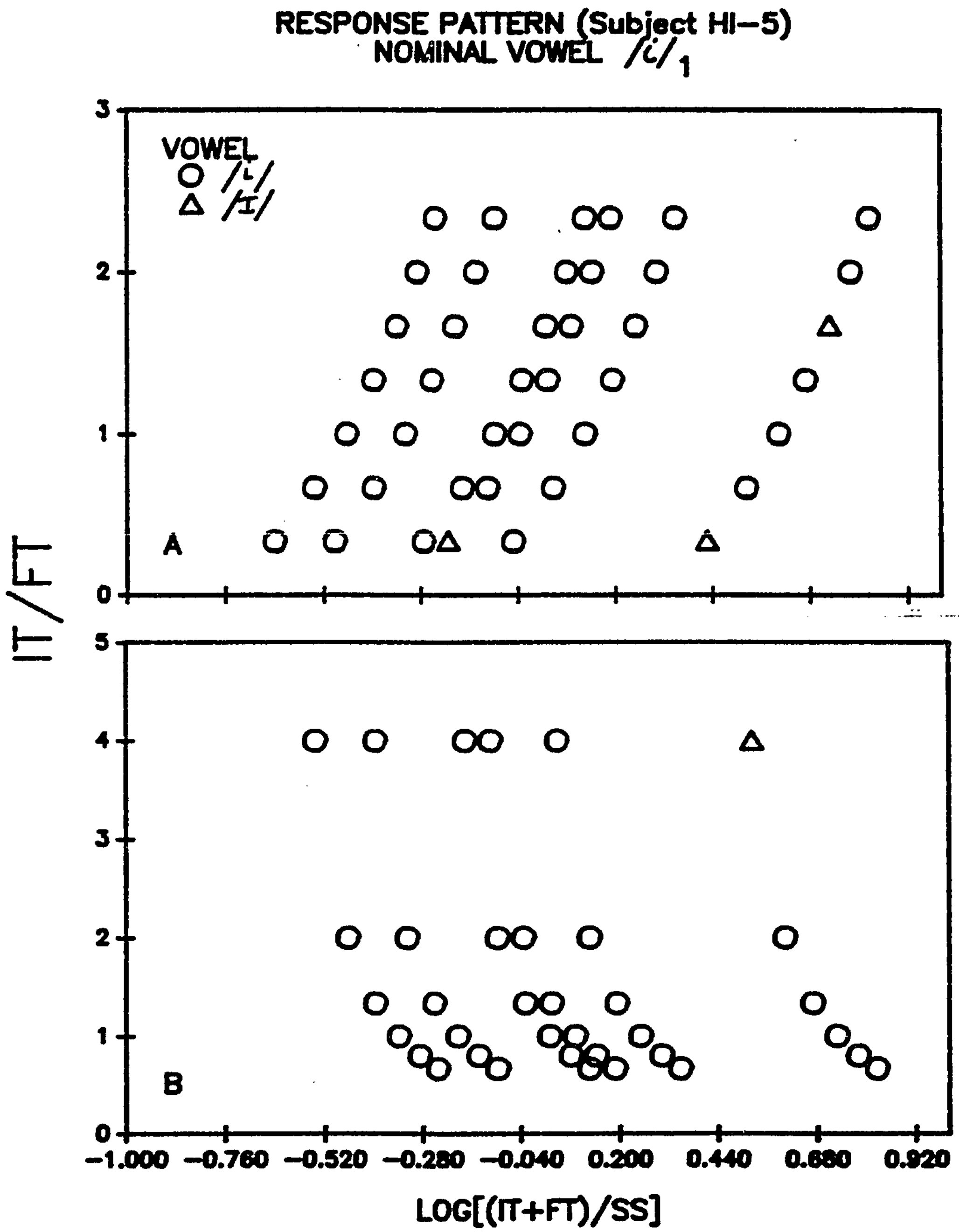

RESPONSE PATTERN (Subject HI-5)
NOMINAL VOWEL /i/1
VOWEL
O /i/
Δ /I/
A
B
IT/FT
0
1
2
3
4
5
-1.000
-0.760
-0.520
-0.280
-0.040
0.200
0.440
0.680
0.920
LOG[(IT+FT)/SS]

Figure 24. Response pattern of hearing impaired subject HI-6. See document for details of the calculation of the indices. The nominal vowel was /i/$_1$. Figure 24a represents the response pattern for a stimulus with a variable initial transition. Figure 24b represents the response pattern for a stimulus with a variable final transition.

RESPONSE PATTERN (Subject HI–6)
NOMINAL VOWEL /i/$_1$

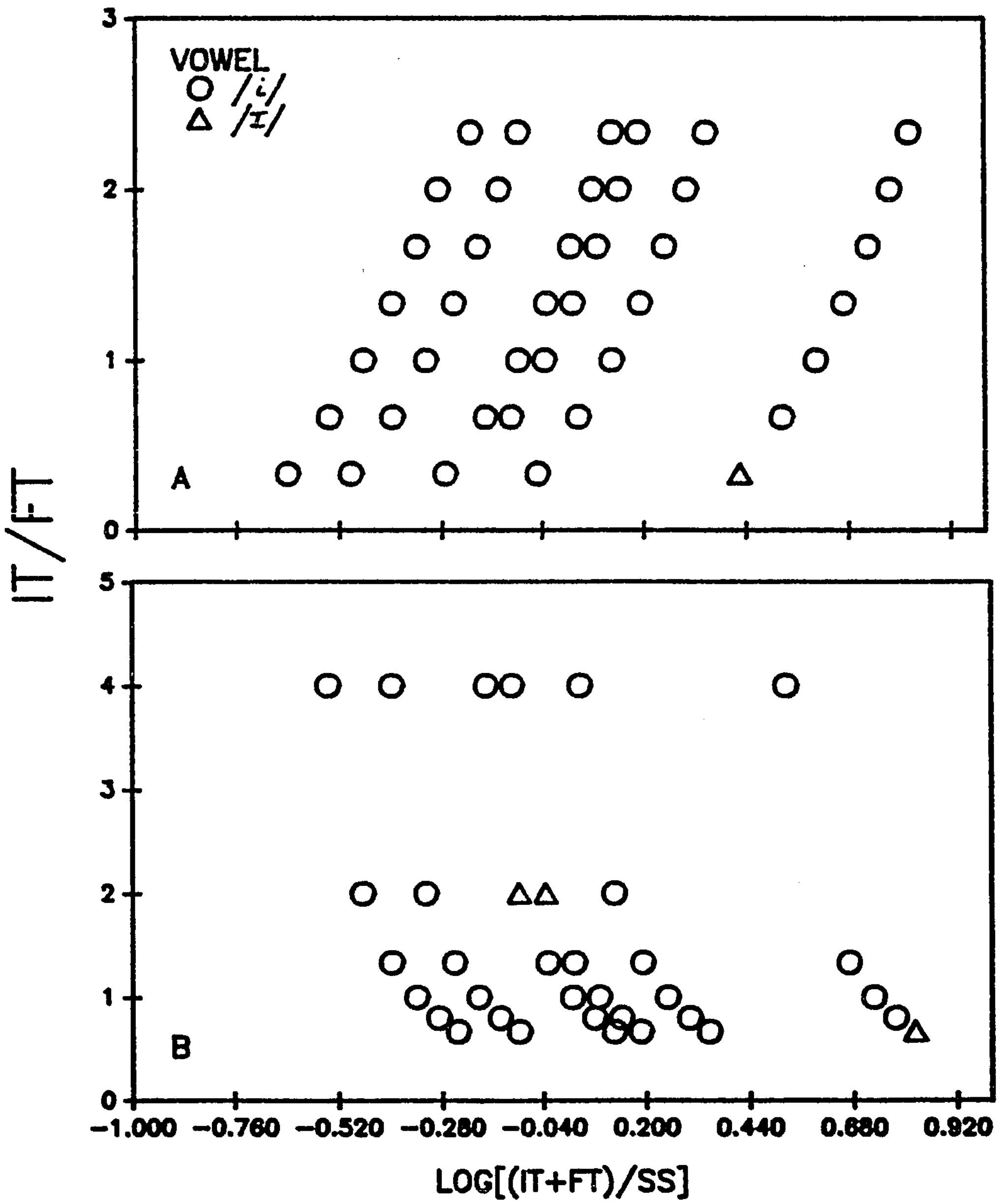


Figure 25. Response pattern of hearing impaired subject HI-3. See document for details of the calculation of the indices. The nominal vowel was $/i/_1$. Figure 25a represents the response pattern for a stimulus with a variable initial transition. Figure 25b represents the response pattern for a stimulus with a variable final transition.

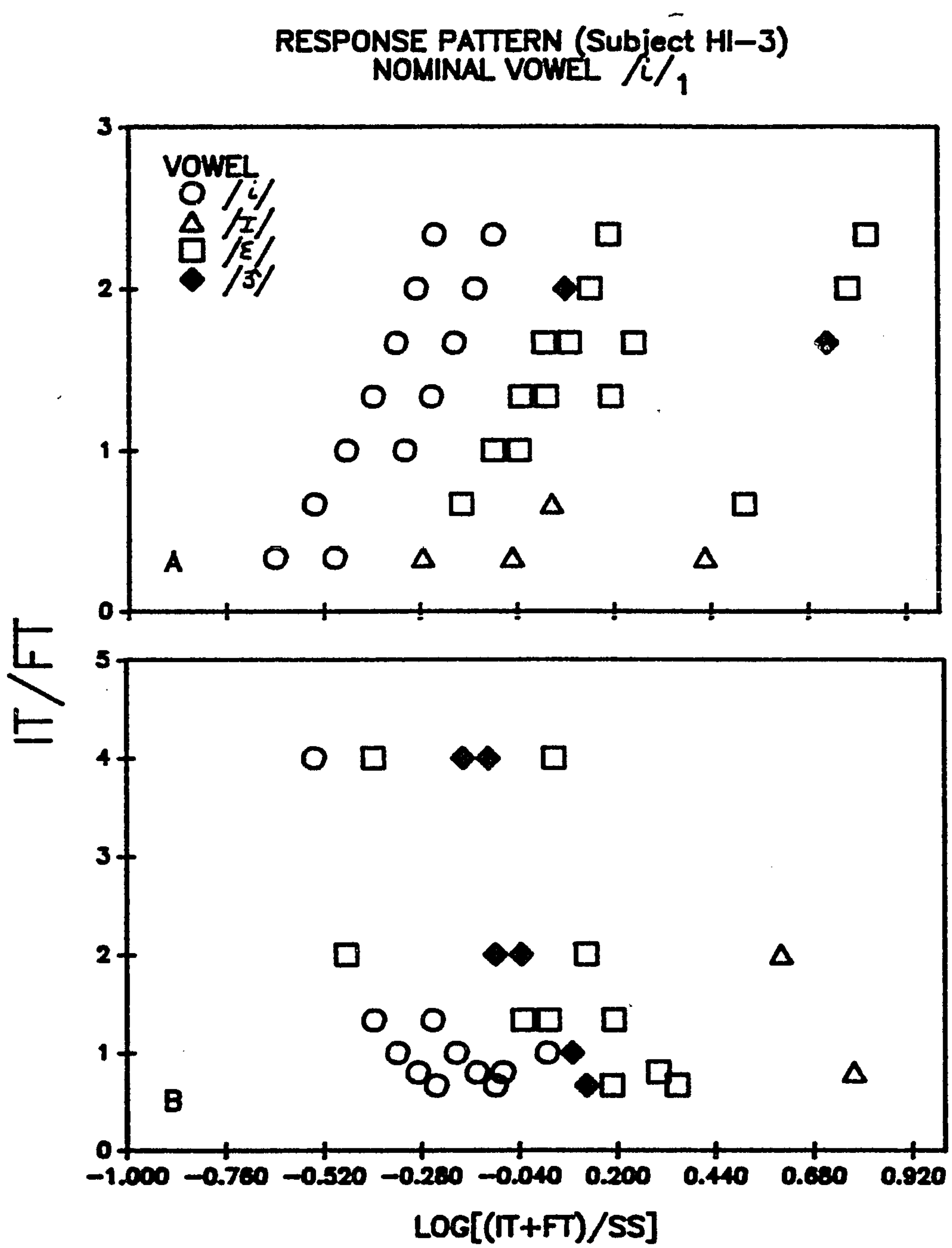
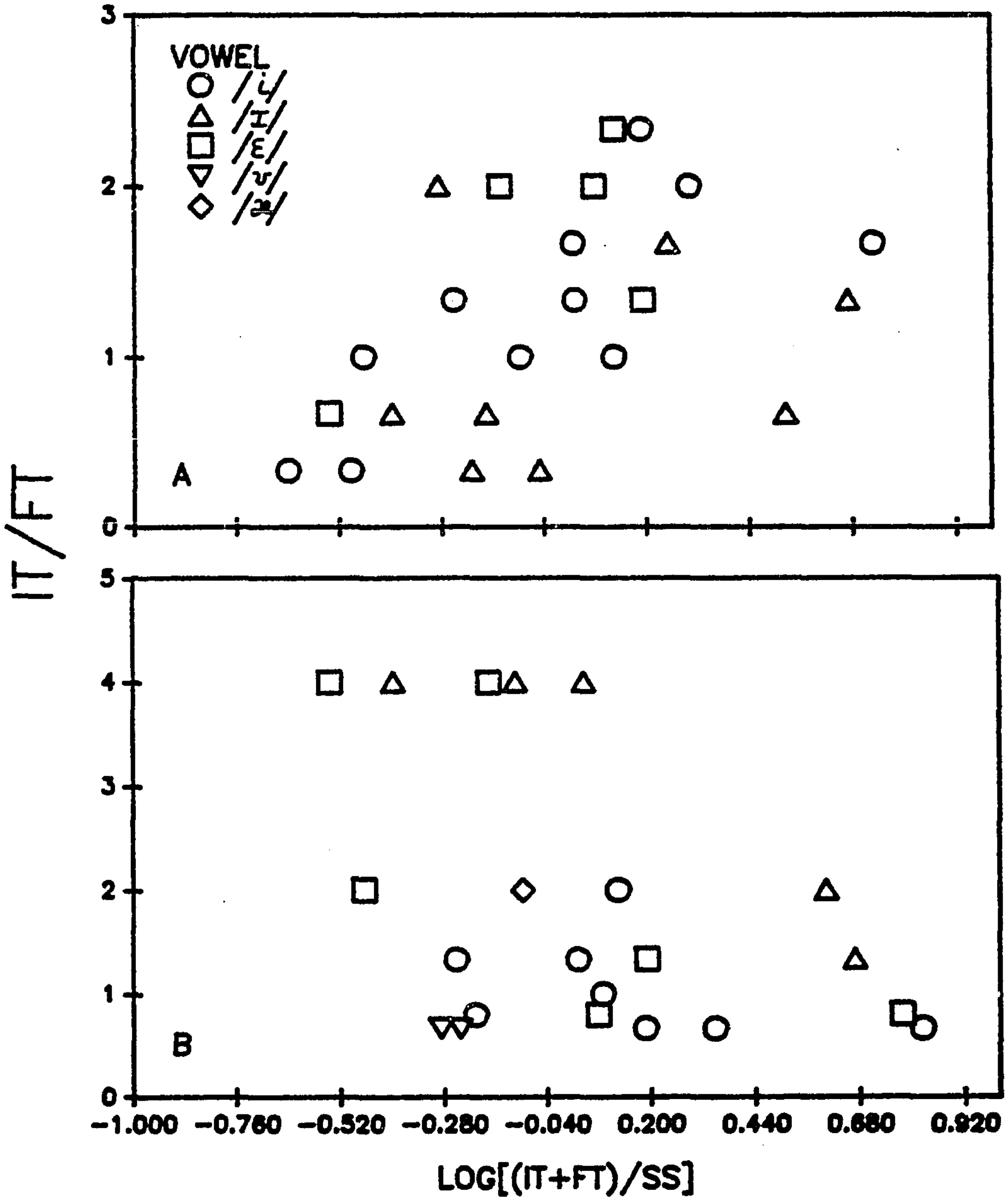

RESPONSE PATTERN (Subject HI-3)
NOMINAL VOWEL /i/1
VOWEL
/i/
/I/
/ε/
/ɜ/
A
B
IT/FT
0
1
2
3
4
5
-1.000
-0.760
-0.520
-0.280
-0.040
0.200
0.440
0.680
0.920
LOG[(IT+FT)/SS]

Figure 26. Response pattern of hearing impaired subject HI-1. See document for details of the calculation of the indices. The nominal vowel was /i/$_1$. Figure 26a represents the response pattern for a stimulus with a variable initial transition. Figure 26b represents the response pattern for a stimulus with a variable final transition.

RESPONSE PATTERN (Subject HI-1)
NOMINAL VOWEL /i/$_1$



not possible to determine the underlying problem(s), it is unlikely that she used a simple weighting or a shift in the use of the various cues.

As with the effects of changes in initial transition duration, there was an effect of final transition duration for the nominal vowel $/i/_1$. In some cases, however, the effects of increasing the final transition duration. When comparing the data in Figures 25a and 25b, it is apparent that the effects of changes in final transtion duration (Figure 25b) was different than the effects of changes in initial transition duration (Figure 25a). Further, if similar comaprisons are made for the responses of subject HI-4 (Figure 21a vs. Figure 21b), there are no differences in the response patterns. Thus for subject HI-4 changes in the initial or the final transition (Figures 21a vs. 21b) appeared to be equivocal with respect to the response patterns.

However, for subject HI-3 the response patterns for the initial transition and final transition conditions were different. Again, there is evidence that some hearing impaired subjects are affected differently by changes in initial vs. final transtion duration and some are affected similarly. Thus, it appears that use of the cue set to label vowel-like stimuli is complex and varies with the stimuli.

Additional support for this complexity may be found in the response patterns for the nominal vowel $/I/_1$ for subjects HI-2 (Figure 27) and HI-4 (Figure 28). It will be recalled that the response patterns for the nominal vowel $/i/_1$ for these two subjects were similar (Figures 21 and 22). Yet as can be seen in Figures 27 and 28, the response patterns for the nominal vowel $/I/_1$ were different. For these two subjects, response differences are evident both within a given subject (Figure 27a vs. Figure 27b and Figure 28a vs. Figure 28b) and across subjects (Figure 27 vs. Figure 28). This result seems somewhat paradoxical; yet it should be considered as further support of the hypothesis that a cue set is fluid in terms of the relative salience of the cues. That is, given that the subjects' hearing sensitivity did not vary, it would seem unlikely that the process of cue extraction and use of a particular cue set would vary with changes in spectral/durational characteristics of the stimuli. However, it appears that the extraction and use of the elements of the cue does change for nominal vowels that are in a lower F1/F2 space ($/I/_1$). It should be noted that these stimuli are in a region of "normal" or "near normal" senstitivity. One possible means to account for this

Figure 27. Response pattern of hearing impaired subject HI-2. See document for details of the calculation of the indices. The nominal vowel was $/I/_1$. Figure 27a represents the response pattern for a stimulus with a variable initial transition. Figure 27b represents the response pattern for a stimulus with a variable final transition.

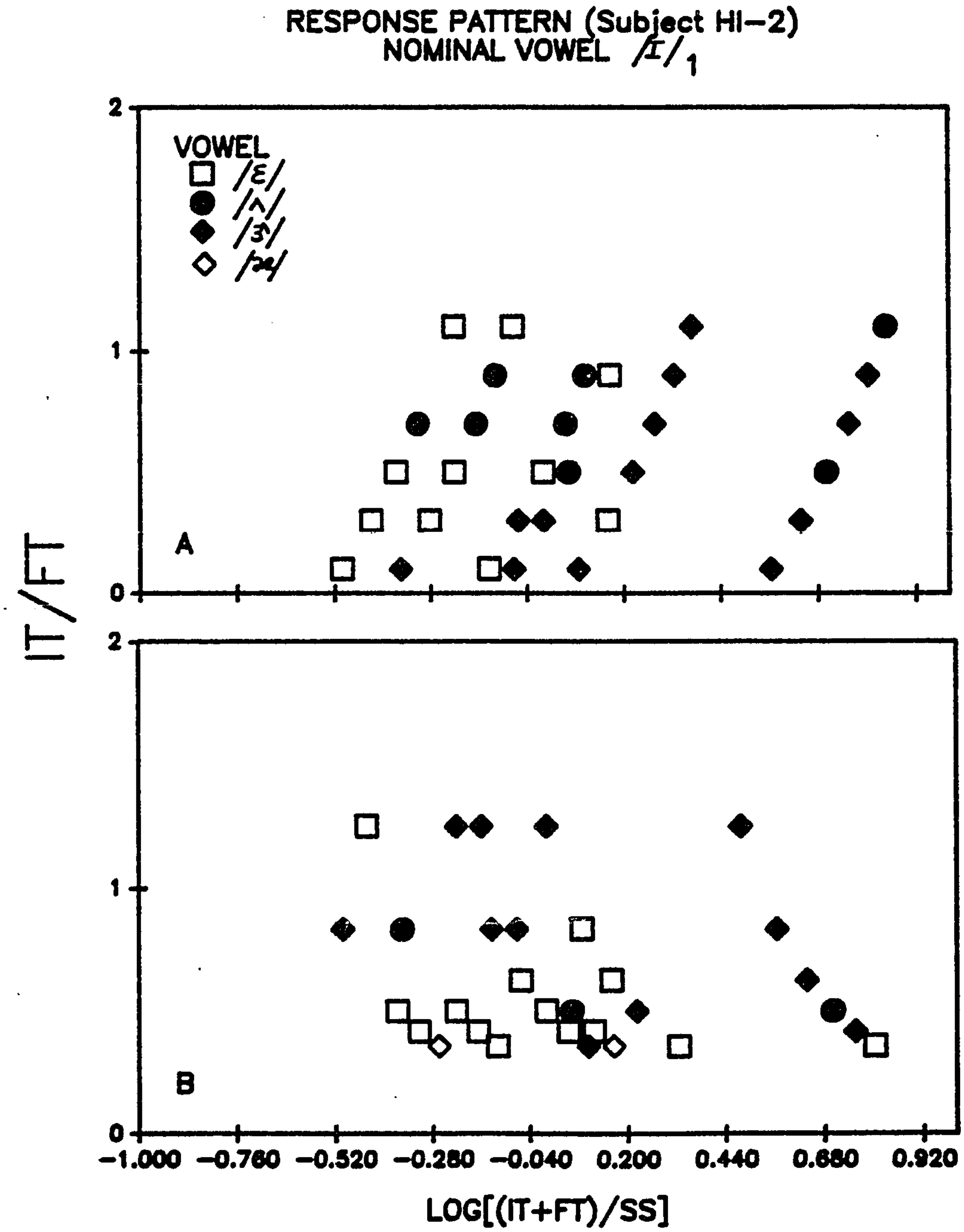
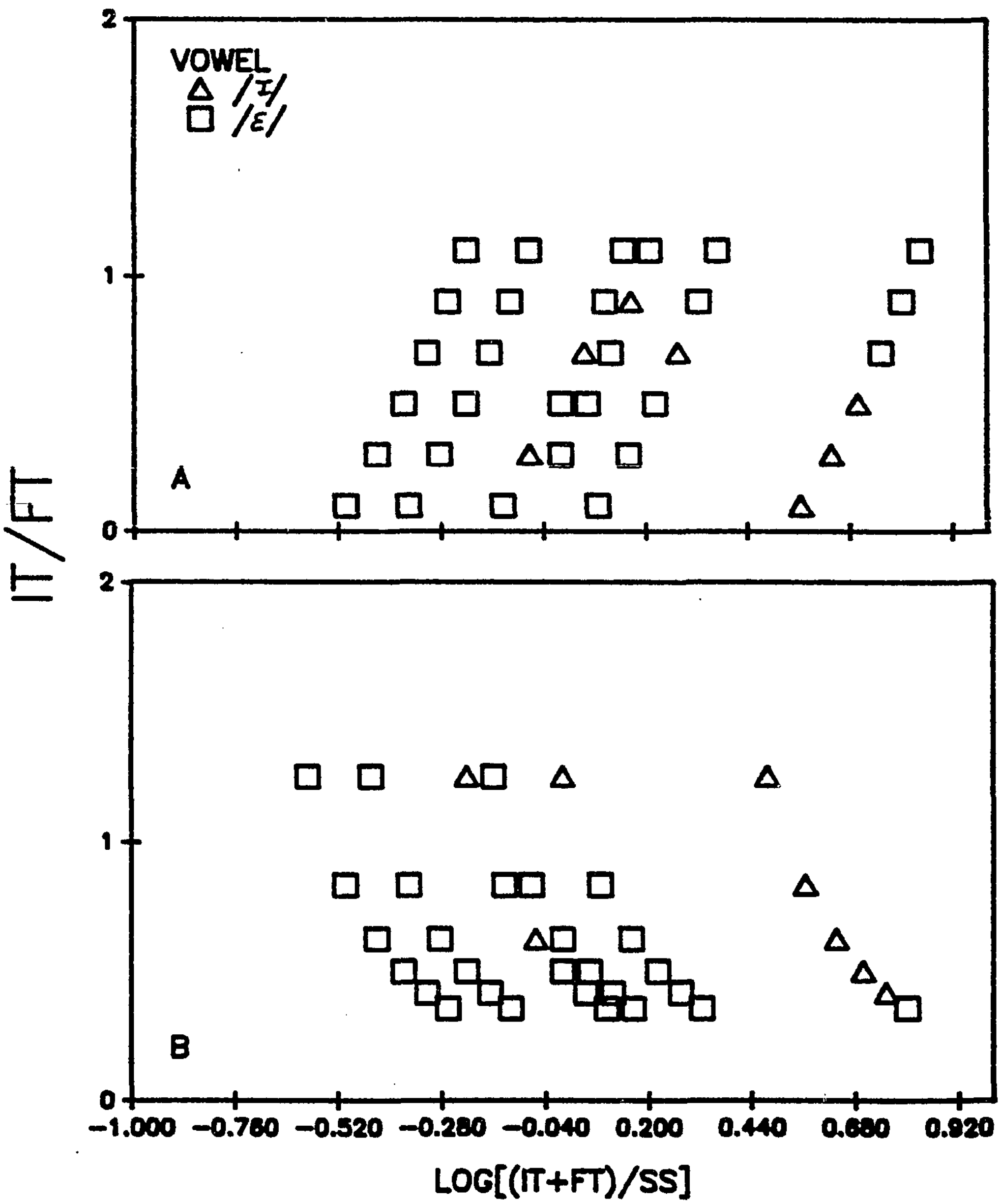

RESPONSE PATTERN (Subject HI-2)
NOMINAL VOWEL /ɪ/ 1
VOWEL
/ɛ/
/ʌ/
/ɜ/
/ɚ/
A
B
IT/FT
LOG[(IT+FT)/SS]
-1.000 -0.760 -0.520 -0.280 -0.040 0.200 0.440 0.680 0.920
0
1
2

Figure 28. Response pattern of hearing impaired subject HI-4. See document for details of the calculation of the indices. The nominal vowel was $/I_1/$. Figure 28a represents the response pattern for a stimulus with a variable initial transition. Figure 28b represents the response pattern for a stimulus with a variable final transition.

RESPONSE PATTERN (Subject HI–4)
NOMINAL VOWEL /ɪ/$_1$



change is to appeal to the previously mentioned complexity and the effects of a set of cues that vary in terms of their relative salience.

It is interesting to note that the degree of hearing loss as measured by pure tones is approximately equal for these two subjects (HI-2 and HI-4). Thus, it would be expected that the subjects would perform similarly, if the only impact of the hearing loss was a decrease in the contribution of spectral cues. However, the response patterns for these two subjects changed in several ways when the nominal vowel $/I/_1$ was in a lower F1/F2 acoustic/articulatory space. That is, differences are noted within the same subject (Figures 27a vs. 27b and Figure 28a vs. 28b) and across the two subjects (Figure 27 vs. Figure 28) and across the two nominal vowels (Figures 22 and 27 vs. Figures 23 and 28). Thus the cue set used by each listener may have been different under each condition (i.e., initial vs. final transition and $/i/_1$ vs. $/I/_1$) or may have been the same while the relative salience of the elements of the cue set varied. It should be noted that the response patterns of these subjects were similar to the response patterns for the normal hearing subjects for the nominal vowel $/i/_1$. However, the response patterns for the hearing impaired subjects were different than the response patterns for the normal hearing subject for the nominal vowel $/I/_1$.

Thus two hearing impaired subjects impaired subjects with approximately equal pure tone senstitivity performed differently. Not only were they different from the normal hearing subjects, they were different from each other when responding to the nominal vowel $/I/_1$. To add to the complexity, these two listeners were similar to the normal hearing listeners and to each other in their response patterns to the nominal vowel $/i/_1$. This seeming paradox is intriguing and raises several questions that remain to be explored. One, are these two subjects using similar cue sets when responding to the nominal vowel $/I/_1$? Two, if the cue sets used by hearing impaired listeners are the same, are the elements affected equally in terms of the distortion introduced by the hearing loss? Three, if "equal" distortion is introduced would different response patterns be related to different strategies? Four, is the distortion introduced by a hearing loss similar across vowels? Five, are the cue sets used by the hearing impaired subjects distorted version of the normal set or are the sets different?

The results of this study can not directly answer these questions. In spite of that, it is apparent from this study that hearing impaired subjects are different from each other and from normal hearing listeners and, therefore, should be evaluated individually. Also, as seen by comparing the response data of normal hearing and hearing impaired listeners, vowel identification is not an errorless process for the hearing impaired listeners. Finally, the use of hearing impaired subjects in studies of vowel perception may permit a glimpse at this complex multi-cued speech perception phenomenon. Specifically, as understanding of the effects of hearing loss on psychoacoustic and speech perception behavior continues to grow it may be possible to model speech perception strategies that are used by both hearing impaired and normal hearing listeners.

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APPENDIX A

LITERATURE REVIEW

The following serves as a review of the literature that is pertinent to the question of the effects of spectral and durational cues on vowel perception in normal hearing and hearing impaired subjects. The literature to be reviewed will be considered with respect to the contribution of 1) spectral cues, 2) durational cues, and 3) dynamic cues. In addition, the literature related to vowel perception by hearing impaired listeners will be reviewed.

Spectral Cues

Traditionally, the most widely held view of vowel perception is one in which listeners extract formant frequency information from the acoustic signal and use that information to identify the vowel. In order to explore this view, investigators have adopted either a direct or indirect method of research.

Direct Approach

Researchers engaged in direct assessments of the vowel perception process typically start with a hypothesis concerning the significance of various spectral cues and explore the effects of manipulating those cues. Specifically, investigators engaged in this type of research have found that changes in formant location or formant amplitude yield changes in perception in the directions suggested by the theory (Delattre, Liberman, Cooper, and Gerstman, 1952). That is, if spectral information was limited the vowels became confused with their near neighbors in an acoustic/articulatory space. Using a slightly different approach, Chistovich and her colleagues also found formant frequency structure to be significant in the recognition of synthetic vowel tokens (Chistovich, Fant, and de Serpa-Leitao, 1967; Chistovich, Fant, de Serpa-Leitao, and Tjernlund, 1966; Chistovich, and Lublinskaya, 1979; and Chistovich, Sheikin, and Lublinskaya, 1979).

Indirect Approach

In using an indirect approach, reasearchers present stimuli and observe response behavior. That is, they do not directly intervene or manipulate the acoustic stimuli; but rather observe changes in responses as a function of stimulus set. This style of research generally leads to an analysis of confusion matrices or response patterns. Typically, the analyses of response behavior was accomplished either by 1) a qualitative description of the responses as a function of spectral characteristics of the intended vowel (Black, 1949, Edmonson and Horowitz, 1950; Peterson and Barney, 1952; Potter and Peterson, 1948; Potter and Steinberg, 1950 and Syrdal and Gopal, 1986) or 2) a multidimensional scaling description (Pols, van der Kamp, and Plomp, 1969; Shephard, 1972; Singh and Woods, 1970 and Wilson and Bond, 1977). Again, the salience of F1 and F2 continues to be the major finding independent of the type of data analysis used

In summary, it has been consistently hypothesized that the salient cues for vowel perception are the frequency values of F1 and F2. This hypothesis has received and continues to receive support independent of the style of research (i.e., direct vs. indirect approaches).

Durational Cues

The research concerning the effects of duration on the perception of vowels will be divided into two major areas. The first area concerns the effects of production on the duration of various portions of the vowels. The second area of literature to be reviewed is one in which researchers observe the effects of durational changes on the perception of vowels.

Production Research

To review the production literature it is helpful to consider the changes that occur in steady state duration and changes in the transition duration as a function of the vowel type. That is, vowels are typically categorized either as tense or lax with the distinction being in part dependent on the intrinsic duration of the vowel (House, 1961; House, Stevens and Paul, 1966 and Lehiste and Peterson, 1961). In addition, Lehiste and Peterson (1961) enumerated differences in initial and final transition durations as a function of the intrinsic duration of the vowel. They, in fact, incorporated the transition duration information in their definitions of the tense/lax contrast. They found lax vowels to have shorter initial transitions when compared to the tense vowels. Also reported by Lehiste and Peterson (1961), lax vowels have longer final transitions when compared to the tense vowels. Also, the transitions deffered in terms of symmetry within either the lax or tense categories. The tense vowels are nearly symmetric in terms of initial and final transition duration, whereas, the lax vowel transition durations are asymmetric with the initial transition being somewhat shorter. Assymetries in terms of the extent of frquency excursions were noted by Stevens House and Paul (1966). Specifically, they found the extent of frequency excursion for the initial transitions to be greater than the excursion for final transitions for tense vowels. In contrast, the frequency excursion was smaller for the initial transition relative to the final transition for the lax vowels. The amount of asymmetry, however, depended in part on the vowel's consonant environment.

Perception Research

As with the review of the literature concerning the effects of spectral cues, the literature to be reviewed here will be divided into two categories; direct and indirect approaches.

Direct Approach. Perhaps the most comprehensive studies concerning the effects of durational cues were completed by Ainsworth (1971, 1981). Using synthetic vowels, he found that duration became an important cue in a cue set if stimuli are ambiguous in the frequency domain (i.e., F1/F2) (Ainsworth, 1971). In other words, if frequency specification is poor, then the duration of the tokens allowed normal hearing listeners to identify more tokens correctly. In attempting to model the interaction of formant frequency structure and duration, Ainsworth (1981) suggested that changes of approximately 250 ms had the same effect on vowel identification as a change of approximately 100 Hz.

Indirect Approach. The studies in which there is a passive observation of the effects of durational cues are those mentioned previously (Peterson and Barney, 1952 and Pickett, 1957). The primary goal of those experiments was to describe the effects of spectral characteristics with only a secondary interest in the effects of duration.

Overall, it is clear that the tense/lax contrast can be cued in terms of absoulte duration as well as transition duration. Further, it appears that durational cues can serve to disambiguate vowels that are confusable in terms of frequency characteristics.

Dynamic Cues

Tiffany (1953) and Strange and her colleagues, among others, have raised questions concerning the adequacy of a simple formant frequency description of vowel perception. The question was originally raised by Strange because her group found that listeners were more accurate in the identification of vowels excerpted from CVC contexts relative to vowels that were produced in isolation

(Gottfried and Strange, 1980; Strange, Verbrugge, Shankweiler and Edman, 1976). This finding was paradoxical because vowels produced in context fail to reach "target" formant frequencies (Lindblom, 1963 and Stevens and House, 1963). Thus if vowel perception depends on matching F1/F2 to some "standard", then vowels produced in context should be more poorly identified than isolated vowels. To resolve this conflict, it was suggested that dynamic information contained in the transitions may be the cue(s) of significance (Rakerd, Verbrugge, and Shankweiler, 1984; Strange, Edman, and Jenkins, 1979; Strange and Gottfried, 1980; Shankweiler, Verbrugge, and Studdert-Kennedy, 1978 and Verbrugge, Strange, Shankweiler and Edman 1976).

With another approach to the same issue (i.e., specification of a cue set for vowel perception), Jenkins, Strange and Edman (1983) and Parker and Diehl (1984) used edited natural speech to gain insight into the contribution of dynamic information to vowel perception. They found high rates of vowel identification in spite of the fact that the steady state portions of the vowels were removed. They concluded, then, that the vowel was adequately specified by the dynamic characteristics because only those characteristics remained in the acoustic signal.

Lindblom and Studdert-Kennedy (1967) also found support for the contribution of dynamic information to vowel identity. They found they could shift category boundaries for /I/ vs. /ʊ/ by varying transition duration. Thus changes in transition duration yielded changes in the identification of vowels. Again, from another indirect approach, Rapheal, Dorman, and Liberman (1980) found that changes in transition duration were integrated into vowel length cues. The integration was apparent because the changes in transition duration yielded a change in the identification of the final consonant.

In summary, it is clear that dynamic cues contribute to vowel identification. Further, the contribution does not appear to be a simple additive effect and the contribution depends in part on the other cues in the stimulus.

Hearing Impaired Listeners

Vowel perception research with hearing impaired listeners has been limited. In particular, Owens, Talbott, and Schubert (1968) and Oyer and Doudna (1957) examined vowel discrimination using monosyllabic stimuli. They found that the error probability for vowel idnetification was low. This, then, would seem to suggest that hearing impaired listeners have relatively little difficulty with vowel recognition. But, there were other elements in the syllables that may have cued vowel identity (e.g., transitions, and phonologic constraints).

If hearing impaired listeners are faced with a reduced or distorted cue set due to their hearing loss, they may be able to use other durational or dynamic cues. However, Pickett and Martony (1980) and Collins (1984) found that some hearing impaired listeners may experience difficulty with processing dynamic signals. Further, the hearing impaired listeners were different from each other in terms of their ability to process dynamic cues. In addition, one listener in the Collins study had differences between his ears in processing these signals.

Thus, within a hearing impaired group there may be considerable variability. This variability may have contributed to the lack if effect observed in vowel discrimination studies. Further, the variaibility found in this group makes it imperative that hearing impaired subjects be evaluated on an individual basis.

In considering the literature with respect to hearing impaired listeners, two points should be made. One, the literature describing vowel identification has been limited in terms of scope and application. Two, hearing impaired listeners are variable in their performance both across subjects and within the same subject.

APPENDIX B

CALIBRATION PROCEDURES

Audiometric Equipment

Pure tone audiometric data were collected with one of two standard diagnostic audiometers (Grason-Stadler, model GSI10 or Madsen, model OB822). Audiometer calibration was conducted according to ANSI specifications (1979). Attenuator linearity and test frequencies were within tolerance limits as specified by the standards.

Pure tone air, and bone conduction thresholds and spondee thresholds were obtained using a standard audiometric procedures Spondees were delivered via monitored live voice by the experimenter. Word recognition stimuli (NU-6 lists 1A, 2B) were delivered via commercially available cassette tapes and presented throught the speech circuit of the diagnostic audiometer.

EXPERIMENTAL EQUIPMENT

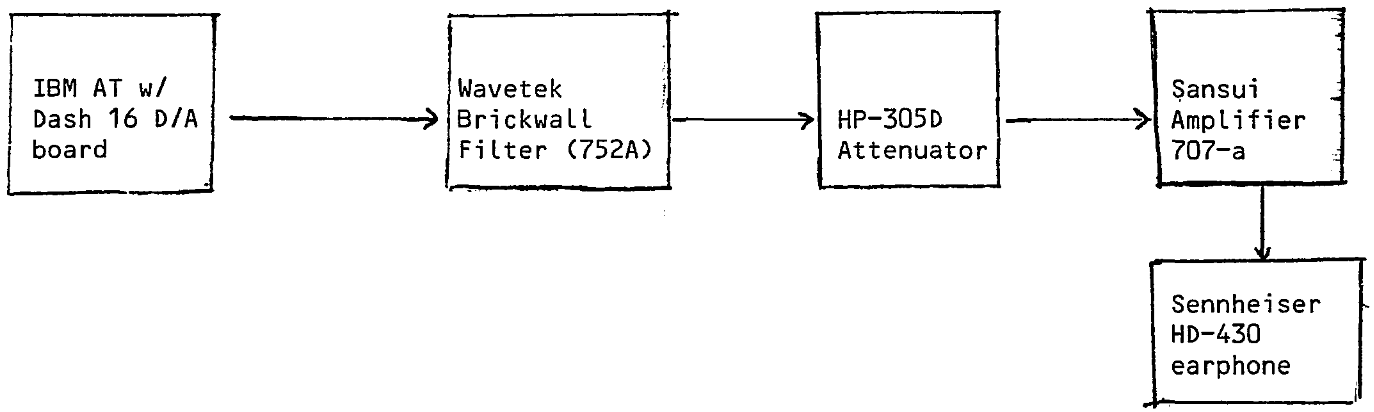
A block diagram of the equipment used for the experimental procedure is provided in Figure B1.

1. Sound pressure level. Sound pressure level calibrations were made through the use of a one-half inch condenser microphone (Larson-Davis model 2559), microphone

pre-amplifier (Bruel and Kjaer, model 2639) and measuring amplifier (Bruel and Kjaer, model 2609). The Measurements were made prior to, during and following data collection. These measurements were found to be in agreement within ± 1 dB. A nominal vowel /i/$_1$ with a steady state duration of 280 ms was used as the stimulus.

2. Frequency response of earphones. The frequency response of the two Sennheiser model HD430 earphones used in this study was established by determining the transfer function of each phone. Quasi-random broadband noise served as the source and the response was evaluated using a Hewitt-Packard model 3561A spectrum analyzer. The frequency response was flat within ± 1 dB from 30-5000 Hz.

Figure B1. Block diagram of instrumentation


IBM AT w/
Dash 16 D/A
board
Wavetek
Brickwall
Filter (752A)
HP-305D
Attenuator
Sansui
Amplifier
707-a
Sennheiser
HD-430
earphone

APPENDIX C

STIMULUS PARMETERS

The synthetic speech stimuli consisted of five formant vowel tokens generated using an interactive program that is a modified version of the Klatt (1980) synthesis routines (Miller, 1980). These tokens were generated on a Perkin-Elmer model 3210 mini-computer. Further, all vowel tokens were generated with a sampling rate of 10 kHz. and a fundamental frequency of 125 Hz.

Table C1 contains the stimulus parameters for the steady state portion of the three vowels (/i/,/I/,/ɛ/) used in this experiment. Each of the three nominal vcwels were generated in three different context conditions. These context conditions yielded differences in F2 frequency locations as might occur if the vowels were produced in a "neutral" context $/v/_3$ a consonant-vowel-consonant $/v/_2$ context or an isolated context $/v/_1$. The formant frequency values for the neutral context and the CVC context for the vowels (/i/, /I/, /ɛ /) were those presented by Stevens, House and Paul (1966). The formant frequency values for the isolated context condition for the same nominal vowels were those of Peterson and Barney (1952). Further, formant amplitude values were those of Peterson and Barney (1952); formant bandwidth values were those of Stevens and House (1963).

In addition to the steady state vowel conditons, stimuli were generated using the same nine formant frequency complexes with the addition of initial and final formant transitions. Table C2 contains a summary of the duration of the initial and final transitions. The endpoint frequencies of the F2 transitions remain fixed for each vowel; the endpoint frequencies are presented in Table C3. These endpoint frequencies were determined using the data presented by Stevens, House and Paul (1966). Because the endpoint frequencies were fixed and the transition duration varied, the transition rates also varied. A summary of the rates is included in Table C4.

The basic corpus of 114 vowels were further manipulated by changing the duration of the steady state. Each of the 114 vowels was edited using a batch style program which was designed to remove portions of the original waveforms. The portions that were removed were integral multiples of 16 milliseconds and they were

Table C1. Formant frequency, amplitude, and bandwidth parameters used in the synthesis of the nominal vowels /i/, /I/, and /ɛ/.

FREQUENCY	/i/	/I/	/ɛ/
Fundamental Frequency	125 Hz	125 Hz	125 Hz
Formant One (F1)			
$/V/_1$	300 Hz	460 Hz	580 Hz
$/V/_3$	280 Hz	450 Hz	530 Hz
$/V/_2$	280 Hz	450 Hz	530 Hz
Formant Two (F2)			
$/V/_1$	2340 Hz	2030 Hz	1880 Hz
$/V/_3$	2220 Hz	2000 Hz	1910 Hz
$/V/_2$	2320 Hz	1740 Hz	1690 Hz
Formant Three (F3)			
$/V/_1$	2920 Hz	2670 Hz	2570 Hz
$/V/_3$	2950 Hz	2650 Hz	2690 Hz
$/V/_2$	2950 Hz	2650 Hz	2690 Hz
Formant Four (F4)	3500 Hz	3500 Hz	3500 Hz
Formant Five (F5)	4000 Hz	4000 Hz	4000 Hz

Table C1. (continued)

AMPLITUDE			
F1	55 dB	55 dB	56 dB
F2	32 dB	32 dB	44 dB
F3	35 dB	35 dB	39 dB
F4	40 dB	40 dB	40 dB
F5	39 dB	39 dB	39 dB
BANDWIDTH			
F1	40 Hz	70 Hz	70 Hz
F2	50 Hz	85 Hz	85 Hz
F3	60 Hz	100 Hz	100 Hz
F4	200 Hz	200 Hz	200 Hz
F5	250 Hz	250 Hz	250 Hz

Table C2. Duration (ms) of initial and final transitions for each vowel token.

	/i/		/I/		/ɛ/	
	initial	final	initial	final	initial	final
Condition						
01	none	none	none	none	none	none
02	16	48	___	___	8	100
03	32	48	8	80	24	100
04	48	48	24	80	40	100
05	64	48	40	80	56	100
06	80	48	56	80	72	100
07	96	48	72	80	88	100
08	112	48	88	80	104	100
09	---	---	40	32	56	52
10	64	16	40	48	56	68
11	64	32	40	64	56	84
05	64	48	40	80	56	100
12	64	64	40	96	56	116
13	64	80	40	112	56	132
14	64	96	---	---	---	---

Table C3. Summary of endpoint frequencies for initial and final transitions for the nominal vowels /i/,/I/, /ɛ/.

Transitions

Vowel	Initial	Final
/i/	1830 Hz.	1980 Hz.
/I/	1670 Hz.	1640 Hz.
/ɛ/	1500 Hz.	1590 Hz.

Table C4. Rates of frequency change (Hz./ms) for the nominal vowels /i/, /I/, /ɛ/ in isolated (#V#), neutral (hVd), and consonant-vowel-consonant (CVC) context conditions.

	Vowel (#V#)					
	/i/		/I/		/ɛ/	
	Transitions					
	Initial	Final	Initial	Final	Initial	Final
01	---	---	---	---	---	---
02	31.87	7.50	---	---	47.50	2.9
03	15.93	7.50	45.00	4.87	15.83	2.9
04	10.63	7.50	15.00	4.87	9.50	2.9
05	7.97	7.50	9.00	4.87	6.79	2.9
06	6.37	7.50	6.43	4.87	5.27	2.9
07	5.31	7.50	5.00	4.87	4.31	2.9
08	4.55	7.50	4.09	4.87	3.65	2.9
09	---	---	9.00	12.19	6.79	5.57
10	7.97	22.50	9.00	8.13	6.79	4.26
11	7.97	11.25	9.00	6.09	6.79	3.45
12	7.97	5.63	9.00	4.06	6.79	2.50
13	7.97	4.50	9.00	3.48	6.79	2.19
14	7.97	3.75	---	---	---	---

Table C4. (continued)

Vowel (hVd)

01	---	---	---	---	---	---
02	30.63	7.08	---	---	51.25	3.20
03	15.31	7.08	41.25	4.50	17.08	3.20
04	10.21	7.08	13.75	4.50	10.25	3.20
05	7.65	7.08	8.25	4.50	7.32	3.20
06	6.13	7.08	5.89	4.50	5.69	3.20
07	5.10	7.08	4.58	4.50	4.65	3.20
08	4.37	7.08	3.75	4.50	3.94	3.20
09	---	---	8.25	11.25	7.32	6.15
10	7.65	21.25	8.25	7.50	7.32	4.71
11	7.65	10.65	8.25	5.63	7.32	3.81
12	7.65	5.31	8.25	3.75	7.32	2.75
13	7.65	4.25	8.25	3.21	7.32	2.42
14	7.65	3.54	---	---	---	---

Vowel (CVC)

01	---	---	---	---	---	---
02	24.37	5.00	---	---	23.75	1.00
03	12.19	5.00	8.75	1.25	7.91	1.00
04	8.13	5.00	2.92	1.25	4.75	1.00
05	6.09	5.00	1.75	1.25	3.39	1.00
06	4.87	5.00	1.25	1.25	2.63	1.00
07	4.06	5.00	.97	1.25	2.15	1.00
08	3.48	5.00	.79	1.25	1.83	1.00
09	---	---	1.25	3.13	3.39	1.92
10	6.09	15.00	1.25	2.08	3.39	1.47
11	6.09	7.50	1.25	1.56	3.39	1.19
12	6.09	3.75	1.25	1.04	3.39	.86
13	6.09	3.00	1.25	.89	3.39	.75
14	6.09	2.50	---	---	---	---

eliminated from the steady state section of the vowel tokens. This manipulation yielded 1254 stimuli which varied in steady state duration from 24 ms to 280 ms. Table C5 contains a list of the steady state durations that were used for all vowel tokens in this experiment. Sample spectrograms of three of the stimuli are presented in Figures C1, C2, and C3. Figure C1 is a spectrogram for a vowel-like token ($/I/_3$) with a steady state duration 72 ms. Further, the initial transition duration was 80 ms. Figures C2 and C3 represent stimuli that are similar to the stimulus represented in Figure C1. That is, the three stimuli differ only in terms of steady state duration. The spectrogram in Figure C2 represents a stimulus with a steady state of 88 ms. Figure C3 represents a stimulus that has a steady state of 184 ms

Table C5. Summary of steady state durations (ms)

Condition	Duration
01	24 ms
02	56 ms
03	72 ms
04	88 ms
05	104 ms
06	120 ms
07	152 ms
08	184 ms
09	200 ms
10	232 ms
11	280 ms

Figure C1. Sample spectrogram of the nominal vowel $/I/_1$ with a steady state duration of 72 ms, an initial transition of 40 ms and a final transition of 80 ms.

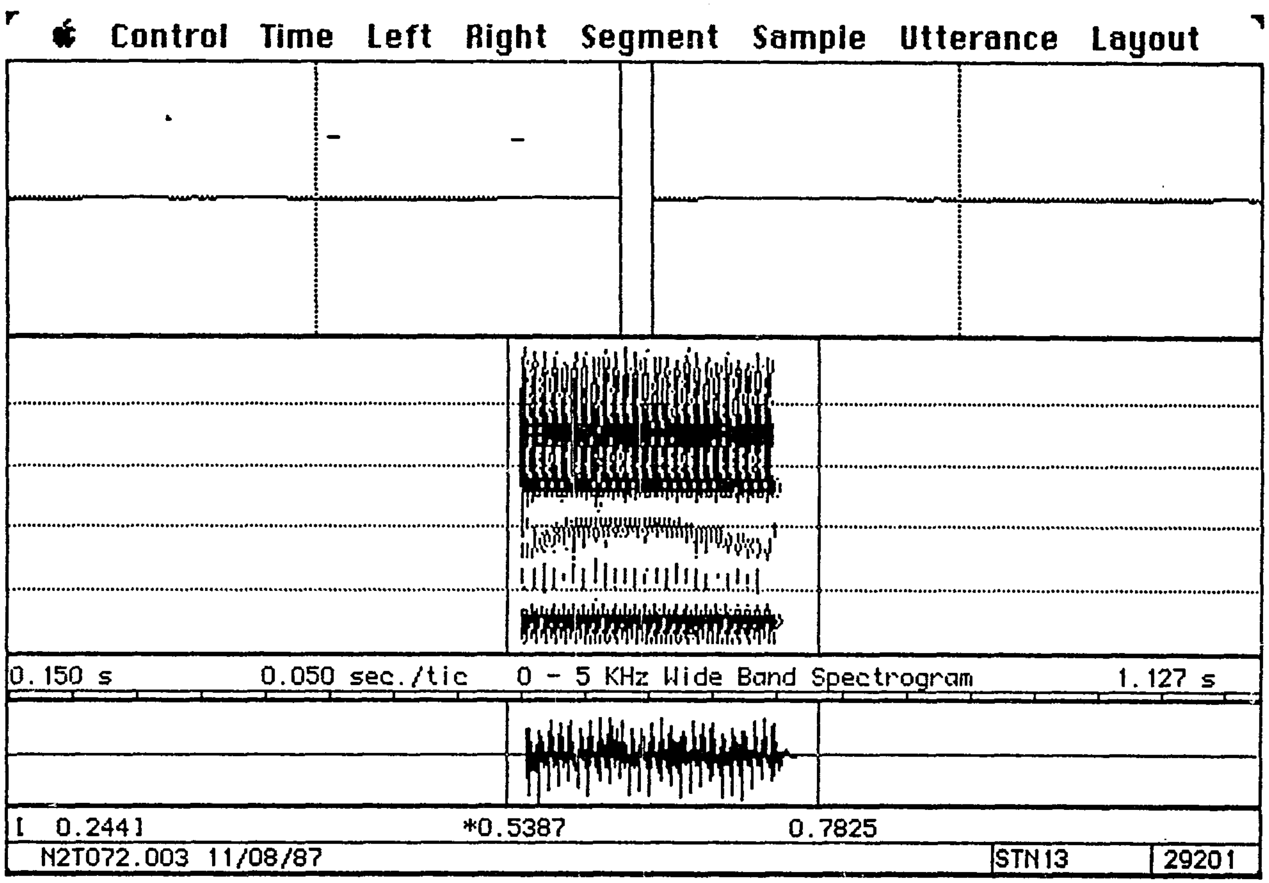

Control Time Left Right Segment Sample Utterance Layout
0.150 s
0.050 sec./tic
0 - 5 KHz Wide Band Spectrogram
1.127 s
[0.244]
*0.5387
0.7825
N2T072.003 11/08/87
STN13
29201

Figure C2. Sample spctrogram of the nominal vowel $/I/_1$ with a steady state duration of 88 ms, an initial transition duration of 40 ms and a final transition duration of 80 ms.

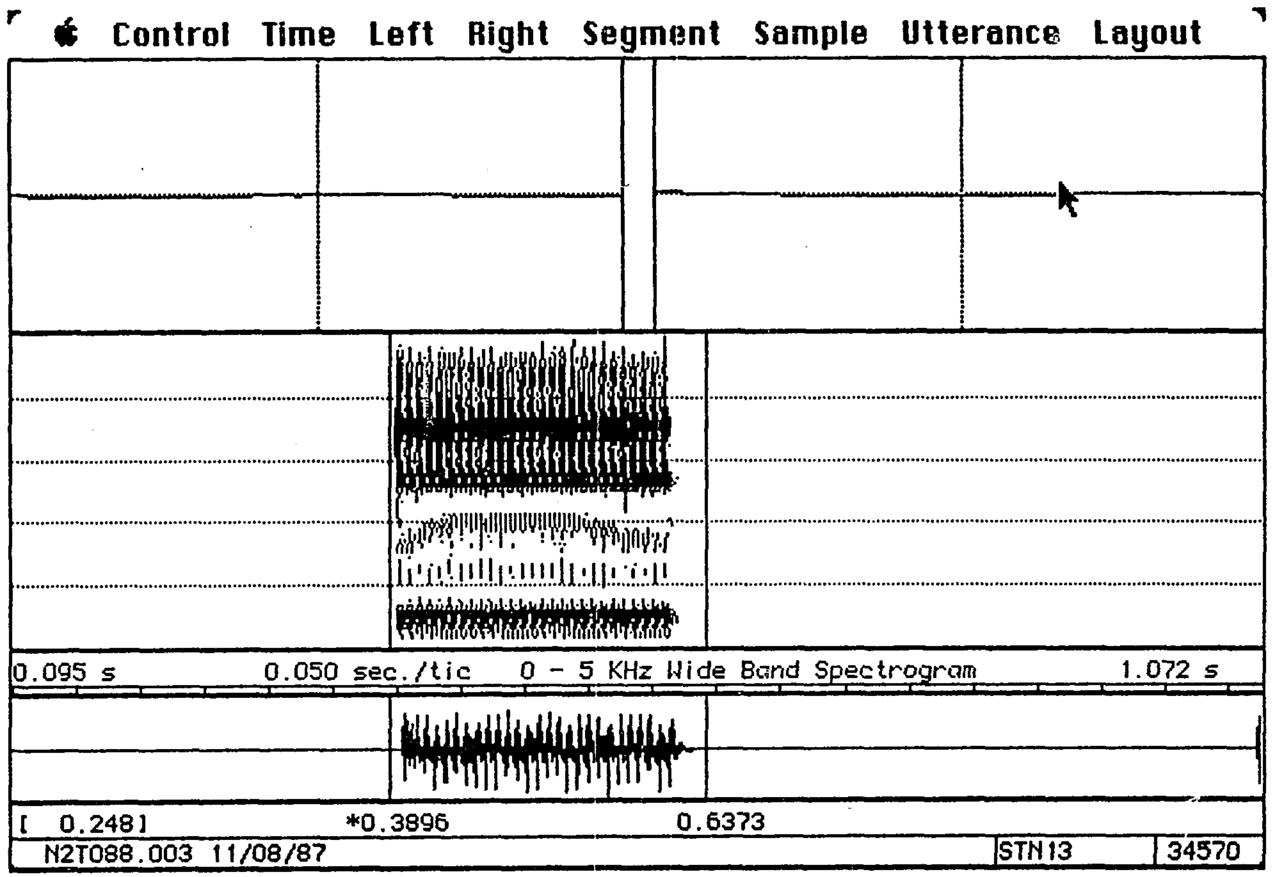
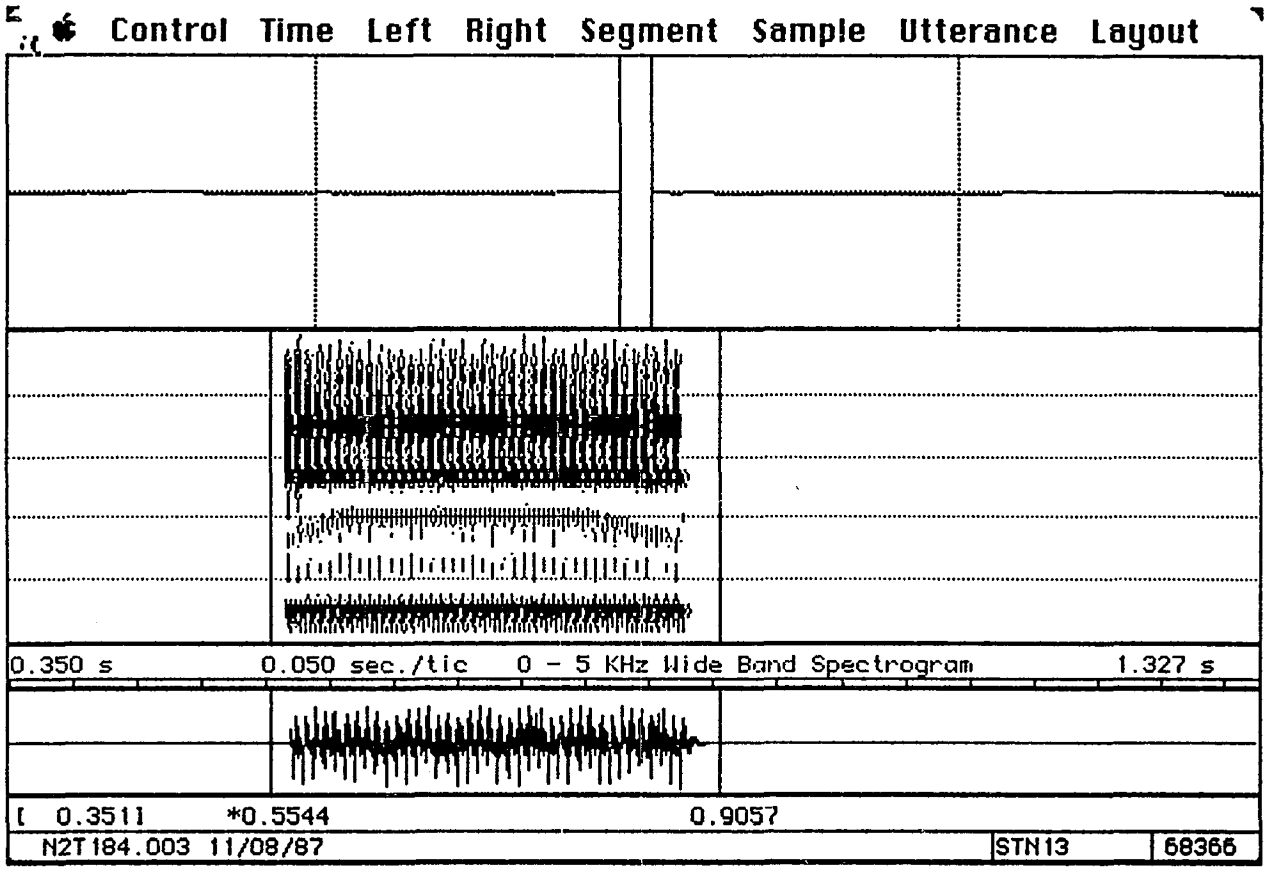

Control Time Left Right Segment Sample Utterance Layout
0.095 s
0.050 sec./tic
0 - 5 KHz Wide Band Spectrogram
1.072 s
[0.248]
*0.3896
0.6373
N2T088.003 11/08/87
STN13
34570

Figure C3. A sample spectrogram of the nominal vowel /I/$_1$ with a steady state duration of 184 ms, an initial transition duration of 40 ms and a final transition duration of 80 ms.


Control Time Left Right Segment Sample Utterance Layout
0.350 s
0.050 sec./tic
0 - 5 KHz Wide Band Spectrogram
1.327 s
[0.3511
*0.5544
0.9057
N2T184.003 11/08/87
STN13
68366

APPENDIX D

RAW DATA

The raw individual data are provided in Wordstar format on the included floppy diskette labeled Aspects of Vowel Perception by Normal Hearing and Hearing Impaired Listeners. The stimuli are coded using the scheme presented in Appendix C with the responses presented in the columns. The column headings are as follows /i, ɪ, ɛ, æ, ɑ, ɔ, ʊ, u/.

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Education

University of Iowa	B.A.	1977	Speech and Hearing Science
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Research Assistant (part-time) Cochlear Implant Project LSU Med. Center under the direction of J. Cullen Fall/Spring 1986-87

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Publications

Published Abstracts

Besing, J., Collins, M.J., and Cullen, J. Duration effects on vowel perception. J. Acoust. Soc. Amer., 83, S70, 1988.

Besing, J., Cullen, J., Porter, R., Rampp, R., and Collins, M.J. Second formant transition discrimination. J. Acoust. Soc. Amer., 81, S35, 1987.

Collins, M.J., Hurtig, R.R., Besing, J., and Schum, D. Identification of voicing contrast via the tactile mode. J. Acoust. Soc. Amer., 78, S47,1985.

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Brunt, M. and Besing, J. Relationship between memory and dichotic listening in children. ASHA, 22, 1980.

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Besing, J., Hurtig, R.R., and Collins, M.J. Vowel perception in noise. Paper presented at the meeting of the Acoustical Society of America, Nashville, TN., 1985.

Schum, D., and Besing, J. Categorical phoneme identification functions in CV and CVCVCV segments. Paper presented at the meeting of the American Speech Language and Hearing Association, New Orleans, LA. 1987.

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